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COMBAT ANALYSIS FOR
COMMAND, CONTROL AND COMMUNICATIONS:
A PRIMER
1993 EDITION

by
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June 1993

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This thesis is a primer for a combat analysis course for Joint Command, Control and Communications students at the Naval Postgraduate School. It provides a single document which ties together the key concepts of combat modeling and analysis.

The thesis introduces various aspects of combat models and illustrates many of their functions, applications and results with examples. Areas included in the primer are: combat theory and the relationship of command and control within that theory, modeling techniques, measures of effectiveness, attrition models, other forms of non-attrition analysis and examples of models currently in use.

The thesis introduces basic concepts and identifies readings from which those concepts were extracted. It does not teach students to develop combat models, although it gives insight into how the application affects proper model selection.

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Combat Analysis for Command, Control and Communications: A Primer
1993 Edition

by

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ABSTRACT

This thesis is a primer for a combat analysis course for Joint Command, Control and Communications students at the Naval Postgraduate School. It provides a single document which ties together the key concepts of combat modeling and analysis.

The thesis introduces various aspects of combat models and illustrates many of their functions, applications and results with examples. Areas included in the primer are: combat theory and the relationship of command and control within that theory, modeling techniques, measures of effectiveness, attrition models, other forms of non-attrition analysis and examples of models currently in use.

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I. INTRODUCTION

This thesis is designed to be a primer for CC3001, a combat modeling course at the Naval Postgraduate School for students in the Joint Command, Control and Communications (C^3) curriculum. It provides the students with a single document that ties together the concepts that the course is designed to teach.

The purpose of this course is to give C^3 students a background in combat modeling and analysis. For instance, one use of a combat model is a "decision aid" for a commander who needs to make some kind of operational or tactical decision affecting the troops under his control. Therefore, it is important for students of C^3 to look at how these models are constructed and how analyses are utilized.

Command itself is evidenced in every aspect of military activity across the spectrum from peace to war. It is not surprising, therefore, that "Command and Control" are seen from many perspectives:

- All levels of policy, strategy, campaigns (or operational art) and tactics,
- Relationships with leadership and management skills,
- As a function to be performed, as a dynamic process, and as a system of tangible and intangible elements.

Moreover, there are current, authoritative documents dealing with one or more aspects of command and control. These documents characterize their own subjects as <u>concepts</u>, <u>programs</u>, <u>structures</u> or <u>doctrine</u>. Older doctrinal publications aside, these new publications fall under self-styled subjects variously denoted as C^2W, C^4I, C^4I for the Warrior, and Information Warfare. Depending

on the issuing agency's authority and responsibility, they emphasize organization, equipment, requirements, procurement, training or operations, either singly or in combination. Some of these documents have indistinct boundaries between wartime and peacetime decision making, the conduct of operations, communications, the use of computers, and intelligence as an organization or intelligence as information. In addition, the domain of applicability and distinction are sometimes unclear between the processes of gathering information, of transmitting it, of using it, and of denying it to the enemy. Inevitably, physical attacks against enemy means of command and active defense of one's own -- thus the actions of combat itself -- enter into some of the activities the documents espouse.

Some of these documents will be studied in subsequent courses. A brief introduction to some of them at the end of Chapter II, will give the student a sense of the sweeping nature of their subject matter, and the variety of perspectives they contain.

Through active duty, most students have acquired a working knowledge of many aspects of command and control and appreciate the problem of describing it so that it can be modeled and analyzed. While horizons were broadened in the introductory course, CC 3000, the C^3 student will be exposed to many more aspects in subsequent courses, principally with the objective of providing a grounding in the design of C^3 (i.e., communications) systems architecture and the development of C^3 systems.

In Chapter II of this primer, command and control will be described and structured broadly as a function, a process and a system. The structure serves two purposes. One is to give the student a very broad framework with which to

compare the many approaches to command in current, operative documents. Since current approaches are not mutually consistent in all respects and in some respects are irreconcilable, the substance of Chapter II necessarily has its own perspective, although it will be seen that insofar as possible, it will conform to common usage and official statements. In time, the student will of course reach his or her own conclusions as to the best fundamental way to think about and analyze specific C^2 and combat problems. In the meantime, Chapter II is to be taken as "doctrinal" for purposes of *this* course.

The objective of this course is not, however, to model and analyze command and control systems. Its objective is to introduce a variety of models and methods that describe and analyze the processes of combat. Therefore, the second purpose of Chapter II is to outline a structure describing combat itself. The combat theory includes "command-control" (C^2) as one process. "Command-control" is the activity that governs all other combat activities under a commander's perview. Another process is "command-control countermeasures" which a commander employs to interfere with enemy command and control activities.

For obvious reasons, the theory of combat is not intended to teach how to win battles. Theory is intended to describe the phenomena of combat so they can be understood. Military analysts understand the wisdom of an old saying that goes: "It's not 'Let's model some battles so we can understand them,' but instead, 'Let's understand how battles are fought so we can model them.'"

Subsequent chapters of the Reader, which contain additional course reading assignments, will address combat modeling and analysis, with more-than-usual attention paid to the role of command and communications. In other words, the objective of CC 3001 is to introduce a variety of models and analytical techniques,

past and present, that describe the dynamic processes of combat and military operations with enough suitability and fidelity to use for decision making. The course treats analysis of operations and battles, not the modeling of the C^2 process; it is about making better decisions, rather than the decision process.

This course outline is divided into nine chapters which deal with separate issues of combat modeling. Chapter II develops a theory of combat to give students a common reference for dealing with combat phenomena. Also in Chapter II is a structure for discussing C^2 that is based on the theory of combat presented. In Chapter III, the student is introduced to the various types of modeling, and the modeling process. Chapter IV deals with selection of measures of effectiveness (MOE), performance (MOP) and force effectiveness (MOFE). In Chapter V, the student is introduced to attrition modeling techniques using Lanchester-type attrition equations. Chapter VI examines the evolution of naval combat and the attrition models that best emulated combat at sea through history. In Chapter VII, non-attrition models are examined and contrasted with the attrition models previously studied. Chapter VIII looks at the current "state of the art," including several combat models located at the Naval Postgraduate School and elsewhere, which have been used for extensive research. A summary is presented in Chapter IX to review the concepts presented and examine the material in view of the follow-on courses the student of Command, Control and Communications will take.

Each chapter begins with an introduction that outlines the objectives of the chapter in simple bullet statements. Outside readings, which supplement the lectures and are contained in the Reader, are listed next. Following the list, objectives are discussed in more detail in order to provide the student with the

general idea behind each objective, so that the student will have a feeling for the important material contained in the readings and how the objectives are related to one another. At the end of each chapter, there is a section on how the chapter relates to other courses within the C^3 curriculum. Finally, there are review questions which should help the student test him/herself on the material presented.

The reading assignment for this chapter is the Fred T. Case paper, "Analysis of Air Operations During Desert Shield/Desert Storm." In 1990, the US Air Force Center for Studies and Analyses completed work on the C^3ISIM model. It was designed to be a tool for analysts' use in the study of Command, Control, Communications and Intelligence (C^3I) related issues. Its first actual use was in the study of drug smuggling activities. However, on 2 August 1990, Iraq invaded Kuwait and soon after the United States began its build-up for Desert Shield/Desert Storm. Consequently, the C^3ISIM model's designers began investigating how the model could be adapted for use in the war as a campaign decision aid.

"Analysis of Air Operations During Desert Shield/Desert Storm" is presented in order to acquaint the student with 1) an actual "working" model, 2) the processes and procedures required to design, and in this case redesign, a model with a real operational purpose, and 3) some introductory terms and theories used in combat modeling.

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II. COMMAND AND CONTROL & COMBAT THEORY

AIM:

Provide the student a background in combat theory, analysis and modeling. Present the student with an internally consistent theory of combat. Present definitions of C^2 and C^3 that support the combat theory. Explore the role of combat analysis in making C^2 decisions to support effective combat.

OBJECTIVES:

- Introduce the role of combat analysis as it applies to command and control decision making
- Explain a theory of combat
    - Define and illustrate two means of "force"
    - Discuss combat processes and how these processes have measurable results
    - Define two different types of combat potential: designed and available
    - Link the concept of combat power on two sides with measurable results and outcome of a battle

- Present the fundamental equation of combat power
    - Provide definitions of Command and Control as a framework for applying the theory of combat
        - Define (1) command, (2) command-control and (3) a C^2 system
        - Discuss the functions of command: organization, motivation, decision and execution
- Distinguish C^3 from C^2
- Discuss role of C^2 countermeasures as they apply to combat
- Discuss the concept of Information Warfare
    - Define C^2W, SEW, C^4I, and the C^4I for the Warrior Concept

READINGS:

1. Hughes, Wayne, Jr., "Command and Control Within the Framework of a Theory of Combat," pp. 1-16, presentation to the AIAA C^3 Symposium, June 1992.

2. Snyder, Frank, *Command and Control: Readings and Commentary*, "Session 1 - Command and War," pp. 11 - 23, 1989.

A. OBJECTIVES FOR COMMAND AND CONTROL AND THEORY OF COMBAT

The purpose of this course is to give the student a background in combat modeling and analysis. The many and varied tools of modeling are not emphasized in this course as much as the principles and application of combat models to the study of military operations. A combat model is valueless until it is applied in some kind of combat analysis. The purpose of combat analysis is to help a decision maker make better-informed decisions concerning his force employment and tactics.

In order to understand how combat models are "built" and used, it is necessary to understand some theory of combat and the unique terms associated with combat. The theory presented in this course outline was developed by The Military Conflict Institute (TMCI) for its general membership and is condensed in this paper.

Forces are elements that perform actions directed against a given enemy element or target. A commander may activate his forces, causing a collection of actions to begin which, in themselves, cause processes that result in some measurable result. The combination of these actions creates an effect on the enemy which is called combat power.

The capacity for forces to successfully engage in combat is called combat potential. The combat potential of forces can be measured in terms of their designed and available potential. The designed combat potential of forces is the capacity of those forces to engage in combat, measured under *ideal* conditions of training, equipment, organization and motivation. The available combat potential is the potential value of forces in the *current* state with respect to training,

equipment, organization, motivation, geographic and weather environment, and specific enemy.

Combat power is the lethal means by which the states of enemy forces are changed. The final results of the collection of processes are a synthesized expression, or measure, called an outcome. Figure 1 is a visualization of the three key concepts.

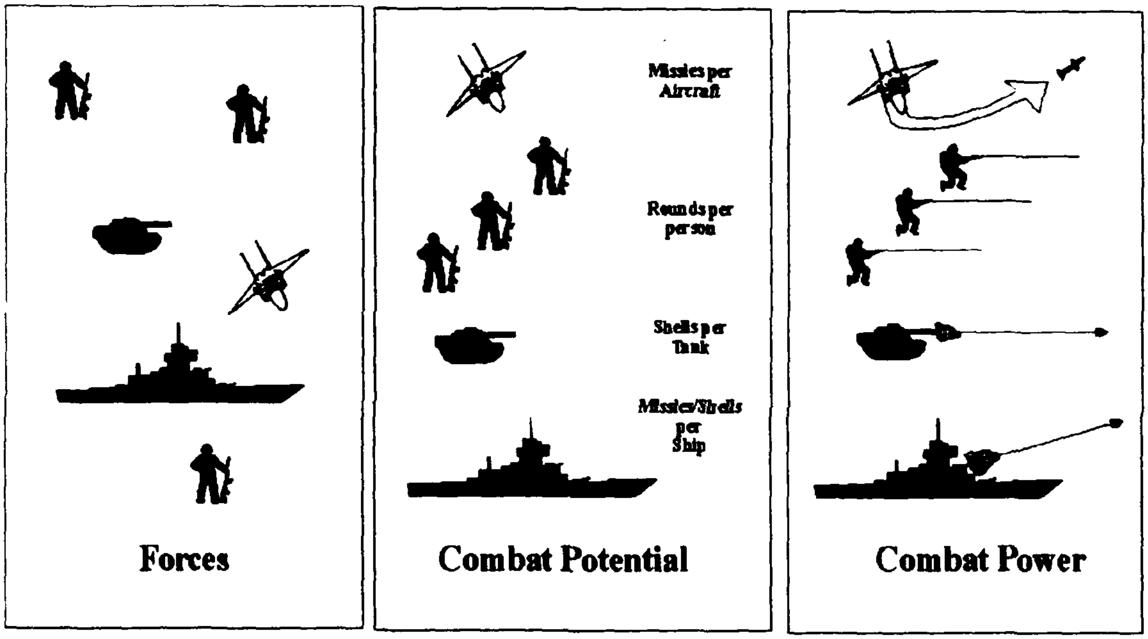


Figure 1

The fundamental equation of combat power expresses how the forces and the actions assigned to each element by a commander are combined to create combat power. The general form of the equation is: $P = F \{m , u\}$, where "P" represents a rate of combat energy delivery that will affect the enemy as combat power, "m" represents the number of forces of a specific type, "u" is the rate of their activity and "F" is the command function that governs m and u.

In order to understand how combat analysis is connected with operational and tactical decision making, the definitions of Command and Control will be structured in such a way to reflect the theory of combat presented. The definition in JCS Pub 1 (see page 17) provides a basis for expanded definitions developed in the next section.

In terms of the theory of combat, command is the function of generating combat potential through a collection of the activities of organization, motivation, decision, and execution. The commander is responsible for ensuring that this function is properly carried out. Command-control is the process by which decisions are reached and orders to activate forces are communicated, so that measurable combat power is created. A command-control system is the collection of personnel, equipment and procedures the commander uses in the process of command-control.

In examining the collection of all processes which both sides employ to generate measurable combat power; C^2 countermeasures are processes that impede the enemy's ability to effectively activate and control his forces, in this way diminishing the enemy's overall combat power.

B. COMBAT THEORY

The theory of combat and definition of C^3 terms are contained in the first reading for this chapter, "Command and Control Within the Framework of a Theory of Combat." The premise of the theory is that combat is a complex interaction of force-on-force activities. The concept is developed by first examining the smallest part of the military organization and building upon this

structure to develop the material necessary to understand the basis of that interaction. What follows is a discussion of some key parts of the paper.

1. Force Functions, Actions, and Activities

Combat functions are responsibilities or roles played by forces. They are the means with which to fight against a notional enemy without any knowledge of who the enemy is or where the battle will take place. The functions are defined independent of the environment in which any battle may occur.

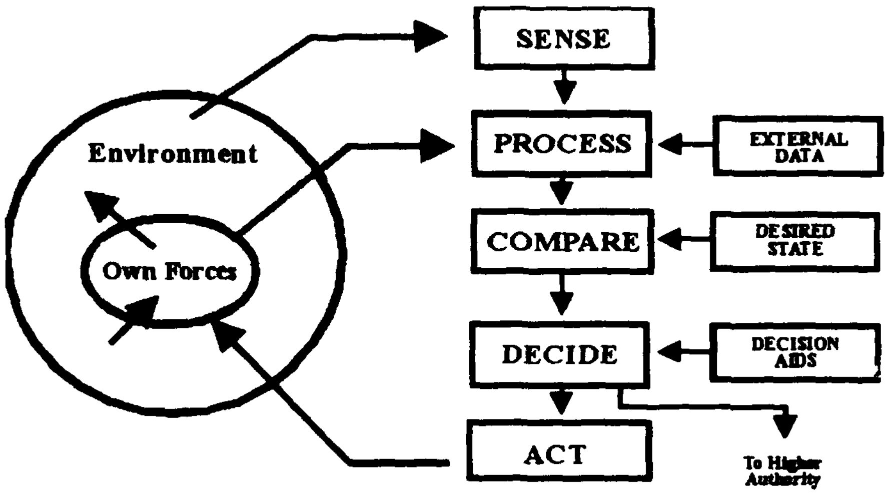
In combat, each element of a force will perform <u>actions</u> based on the function assigned to the element (by command), the current state of the element (capability of the element at a given time) and the attributes of the element. For example, an AAW unit will perform actions against enemy aircraft, but it is not expected to take effective action against enemy infantry or armor. The effect of the actions taken by the element is to cause some change in the state of the enemy as well as the unit itself. This change in state caused by an <u>element-action-element</u> exchange is known as a <u>combat activity</u>. The result of these activities is some change in the receiving element's state which can be measured. For example the effect of an AAW unit firing at an approaching aircraft is a depletion of ammunition for the firing unit and a possible loss of aircraft for the enemy. Actions such as the delivery of fire can be quantified and measured, but combat results come from activities that include the object element.

Note that to this point we have talked only about the effects of one side upon the other. The second side is also usually delivering fire in return, so that there is a total force-on-force effect.

2. Combat As A Collection of Processes

The collective activities of the forces on both sides are combined into a combat process which can be measured as results. The collective lethal actions of the elements of a force and the countermeasures employed by the enemy have observable net effects (such as attrition, suppression, retreat or other movement) on the enemy elements. The *results* of activities (element-action-element) are the new states of the delivering and receiving elements.

The most common form of studying the command-control decision process is through use of the Lawson-Moose C^2 Cycle (Figure 2). In this cycle, the commander observes the environment around him. The environment contains friendly and enemy forces, terrain and weather. The only way the commander can affect his environment is through the actions of his own forces or through command-control countermeasures, which may cause the enemy to react directly as a result of those countermeasures. The C^2 process steps are: sensing the environment, processing the sensed information, comparing present state to the desired state, using decision aids in deciding upon the course of action to take, and then acting upon that decision. Through the C^2 process the commander is able to employ his forces effectively against the enemy and hopefully achieve his objective.



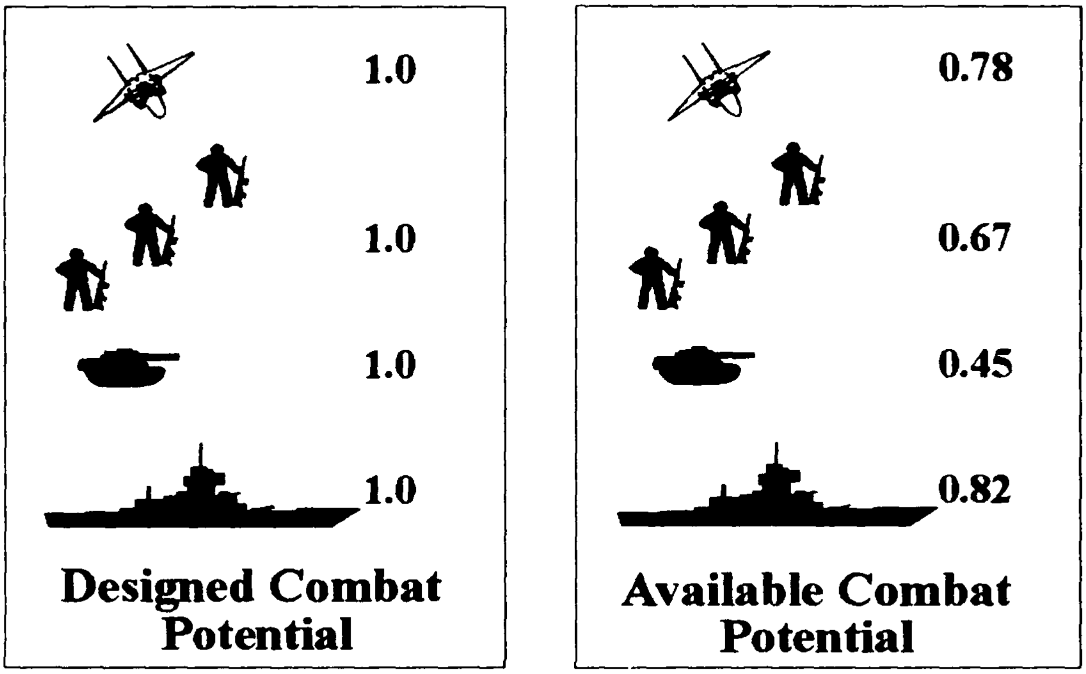
Lawson-Moose Model of the C2 Process

Figure 2

3. Combat Potential

The capacity of a given force to fight is called its combat potential. There are two types of combat potential which describe the state of a force. Its designed combat potential is the capacity of a given force to be effective in combating the known enemy, given *optimal* training, equipment, motivation, organization and leadership. Designed potential assumes that the forces perform as designed and intended, with complete understanding of who the enemy is and the geographic location of the battlefield. With perfect information the force would be optimally fitted to the specific battle. The available combat potential of a force is the current capacity of a force to combat the actual enemy, given *existing* levels of training, equipment, motivation, organization and leadership. Obviously, the capacity for a force to conduct warfare at any given time against a specific enemy will be less than its designed capacity due to imperfect levels of training, equipment, organization, and an imperfect knowledge of the battlefield location

and character of the enemy. The available combat potential will thus be measured as some factor between 0.0 and 1.0 of the designed combat potential (Figure 3).



Designed versus Available Combat Potential

Figure 3

4. Measurement Of Combat Power

The lethal effectiveness delivered by forces is a result of those forces being activated by command against an enemy. This is the quantity called <u>combat power</u> and is a result of forces engaging enemy forces at a given time and location. Combat power is generated by forces carrying out combat actions against the enemy, based upon a commander's activation of his forces utilizing a command-control process. Combat power is generated from the available combat potential of the forces similarly to the way that energy is consumed from a battery during its

use. Combat power is measured by the amount and kind of change in enemy states. The change takes place on both sides simultaneously.

5. Fundamental Equation Of Combat Power

Having an understanding of combat, the next step is to develop an equation for determining the relationship between the entity we desire to measure -- combat power -- and the independent variables involved. The fundamental equation of combat power for tacticians and theorists is of the form: $P = F \{m , u\}$.

The quantity, combat power (P), derives from the mission-specific relationship between force elements (m) and the kind and time rate of their activities (u). The function (F) governs the pattern of the elements' activities, so it is called the command function. In other words, when the commander activates his elements of combat potential, the "pattern" is the tasks they perform. Pattern is meant to be what each element is doing (firing, scouting, maneuvering, communicating, etc.), where it's doing it (flank, front, rear, enemy's rear, entrenched, etc.) and how well it's doing it (rate of fire, rate of search, speed of movement, effectiveness of communications, etc.). Since activities and combat power usually have a geographical direction or orientation, they may be shown as vectors.

In an operational sense, it is the pattern as well as the number of forces and rate of activity that determines the combat power of one side. In the analytical sense, a model that best describes the pattern of activity is chosen and is used to compute the quantity of combat power delivered.

The effect of side A's combat power on side B, however, depends in part on defensive actions by B's elements (entrenching, jamming, evasion, withdrawal, etc.). This is why we must distinguish combat functions ordered and performed by

side A (which create raw combat power) from the two-sided process that determines the effective combat power (or "force" as *it is often called in the* literature). Effective power by side A causes observable results, such as casualties to B, or his suppression, retreat or surrender.

B's countermeasures to lessen the effects of A's combat power are not the same as B's offensive activities that generate his own combat power against A. Combat is a force-on-force activity because A and B are both creating combat power and attenuating the effect of their opponents' combat power.

It is the role of a commander to (a) govern the pattern of his forces' activities and (b) do so with regard for the probable pattern of enemy activity. It is the role of a combat analyst to discern probable patterns of both sides and model them in a way that will result in better command decisions.

C. COMMAND AND CONTROL

1. Definition Of Terms

As a starting point, take the JCS Pub 1 definition of command and control:

> The exercise of authority and direction by a properly designated commander over assigned forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities and procedures which are employed by a commander in planning, directing, coordinating and controlling forces and operations in the accomplishment of the mission.

Refer to your second reading assignment, Frank Snyder's *Command and Control· Readings and Commentary*, Session 1: Command and War, pp. 11-23. In it, Snyder points out that the JCS definition contains three different notions. The first is the concept of a function, or responsibility. The second idea is that of a

command-control process that performs the function. The third idea contained in the definition is the physical entities that make up a command-control system.

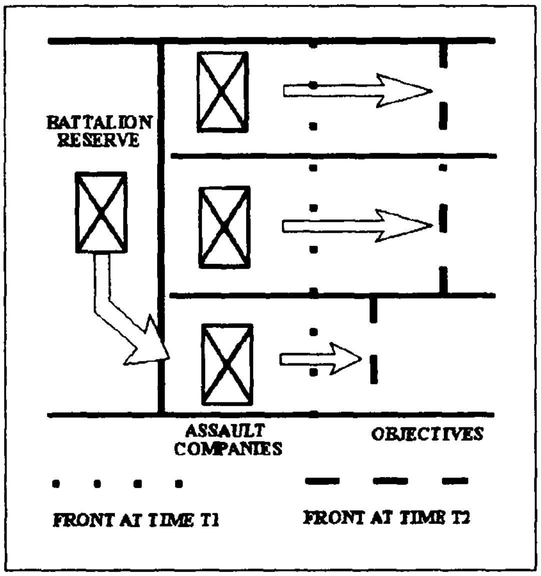
2. The Function Of Command

Command, as taken from the JCS definition, is the all encompassing responsibility associated with "the exercise of authority and direction by a properly designated commander." To command a force, from the inception of that force, to the execution of operation orders, requires functions including: organization, motivation, decision and execution. Other responsibilities of command such as training and education may be considered as a subset of the four categories.

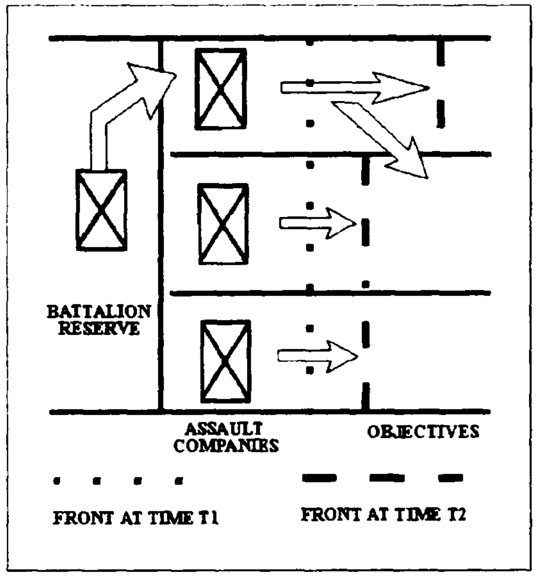
In light of the theory of combat, command is the all encompassing function which generates the designed and available combat potential. Through the sub-functions of organizing, motivating, deciding and executing, a commander brings his forces from some untrained or otherwise unready condition to a point where the available combat potential of the forces is as near as possible to its designed combat potential. The readiness of the forces prior to executing an operation is the responsibility of commanders at many echelons and is accomplished through the function of command. Yet, at all times, the commander must be ready for and expectant of change, be it in his own force's or in the enemy lines. Take for example the following battlefield scenario (Figure 4).

The commander is in charge of four elements, three assault companies on the front line and a reserve battalion held in the rear. There are two ways that he may decide to utilize his forces. He may decide to reinforce the weaker company, thereby endeavoring to present a balanced front to the enemy. Or he

may direct his reserve towards the company making a breach in the enemy lines, thereby hoping to exploit a breakthrough.



Reinforcements are Sent to the Company on theRight Flank which is Having DifficultyReaching its Objective



Reinforcements are Sent to the Left Flank to Exploit the Opportunity of a Breakthrough

Figure 4

3. The C2 Process

We can also see that the JCS definition includes a "process employed by a commander in planning, directing, coordinating and controlling forces in the accomplishment of the mission." These are the actions taken by the commander to transform the combat potential of forces into the realized combat power resulting from carrying out mission orders.

It is important for the theory of combat to distinguish command-control as a process of transformation, not just a function, or responsibility, to govern everything under a command. The command-control process occurs only when the elements are part of the command-control system and the measured actions carried out by the elements are part of the command-control process. Command-control cannot be thought of as everything involved in combat. The activity of ordering a battery to fire weapons is the command-control process. When the artillery fires, and results are achieved on the enemy, that is called combat. Command governs all the actions of its forces, but command-control is not everything in combat. Combat is the all encompassing term.

4. Information Collection

Some definitions of command-control include information gathering. We do not. The process of information gathering, including detection, classification, tracking, targeting, etc., should be given status distinct from C^2. Indeed, how the decision is made to distribute forces to collect this information is a vital decision which a commander must make. How the information is interpreted once collected, and deciding what actions will be taken, based upon the information, is indeed a command-control process; but the action of collecting the information is best thought of, not as part of command-control, but as a separate process in its own right: information collection. This point is extremely important in current command-control problems as we will see later.

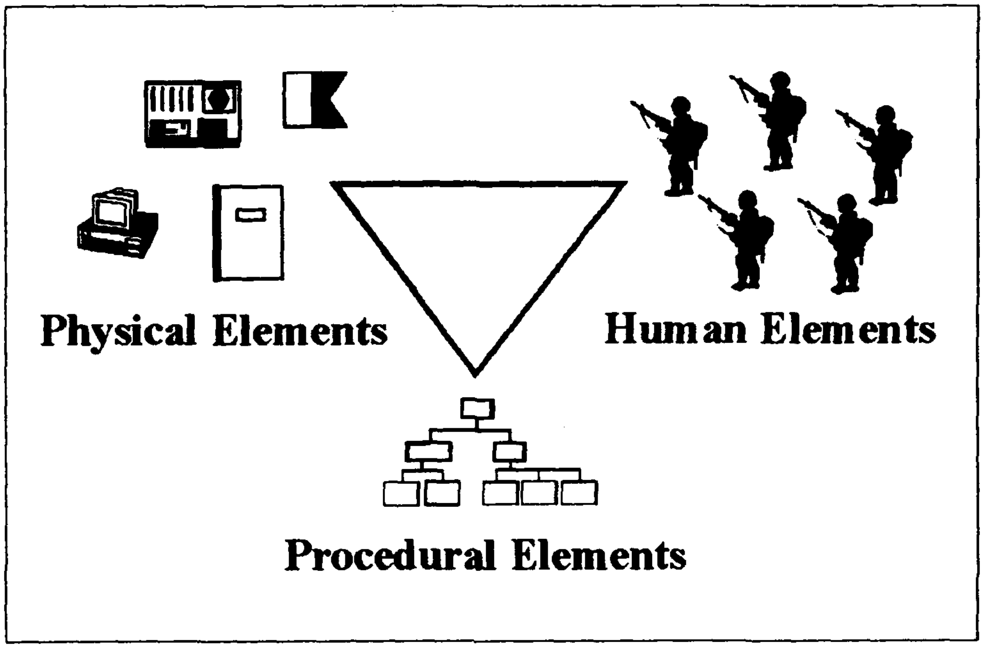
5. A Command-Control System

Having presented definitions for the command function and the command-control process, the third step is to define a command-control system. The JCS Pub. 1 definition includes a definition of a C^2 system: "..the arrangement

of personnel, equipment, communications, facilities and procedures which are employed by the commander..". A command-control system contains all the tangible items used to perform the command-control process. The command-control system then is composed of:

- Physical elements -- transmitters used to broadcast orders, signal lights and flags, computers, code books and tapes, deciphering equipment, etc.;
- Human elements -- the commander himself, communications staff, military analysts in the chain of command, etc.;
- Procedural elements -- used to conduct the process -- training manuals, equipment manuals, procedural manuals for a fleet, organization charts and command relationships.

A command-control system is used to facilitate the process of command-control (Figure 5). It is important to note the inclusion of the commander in the system definition. Without a commander to make the decisions, the system cannot perform its function, so we must include the commander as part of the very system he uses.



Command-Control System

Figure 5

6. Role Of Command-Control Countermeasures

If we define command-control as the process of transforming combat potential into combat power, then command-control countermeasures are those activities which reduce the effectiveness of the enemy's command-control. These countermeasures cause the enemy's command-control elements to be less effective, such as jamming radios, providing misleading intelligence and destroying his command centers.

D. MODELING AND ANALYSIS

It was during World War II that military operations research gained its place as an emerging science. After the war, the writings of Philip Morse, George Kimball, P. M. S. Blackett and others who had analyzed military situations and phenomena spurred the creation of modern military operations research. They

encouraged analysis that used scientific principles applied to the environment of combat because they had themselves seen how effective OA (Operations Analysis) could be in developing better tactics and operations.

Prior to World War II there was no school of thought or formal organization devoted to analysis of military actions or conditions, but during World War II scientists "went to war." Some became involved very early in field operations, most notably with radar in the Battle of Britain. From there it was natural that they should involve themselves with the tactical employment of sensors and weapons. Thus operations research was born. The works of Morse and Kimball, presented in *The Methods of Operation Research*, 1946, still stand as a cornerstone in the field.

A model, applied to any situation, is merely a "simplified representation of the entity it imitates or simulates." The goodness of a model lies in how well it achieves its purpose. The two major purposes of models are better decisions and better training. But despite some current efforts to use computer power (e.g., virtual reality, SIMNET), models cannot reproduce war, and attempts to do so have led to overwhelming complexity with little to show for it. Complexity per se has little to do with utility, in practice.

A feature of good modeling is that the model is prepared with a specific need in mind to serve the client for whom the model is built. In the case of military modeling, the client may be, for example, the Joint Chiefs of Staff which desires to have a model created to explore the effects of theater ballistic missile defense. We say the model is "decision oriented."

In developing models, there are general steps which must be taken by the client as well as the analyst. In *Work and Method of Operations Analysis*, Robert Dorfman categorized the steps involved in analysis as:

- Perception,
- Formulation,
- Observation,
- Analysis,
- Presentation.

Perception. For the purposes of this course, the client will be taken to mean a person in a position of command who must make decisions. Perception of the problem as put forth by a client and as understood by the modeler, lays the basis for providing a useful model as a tool for analysis. The modeler needs to understand the context for which the model is being developed. Most analyses are not intended to give a single solution as end products. Typically, the result is an IF-THEN statement: if such-and-such are the inputs, then so-and-so will be the results.

Formulation. Formulation of the client's problem is accomplished by means of four actions. First, determine the objectives of the operation. Second, list the alternative courses of actions. Sometimes the list must include both one's own and the enemy's choices. Third, define a measure of effectiveness by which to compare the alternatives. Fourth, determine the variables that are regarded as critical and figure out how they interact so that the relationships can be modeled during the step called analysis. An agreement on the problem statement, the data available for the model and the assumptions which will be made, are necessary in this step, prior to collecting the data and modeling the client's needs.

Observation. The next step requires collecting data to be used in the model and the environment which the model is attempting to emulate. This may often cause a reformulation of the problem, if obvious changes are required to accurately describe the environment.

Analysis. During the analysis step, the analyst combines his working model with the observable data in such a way that "models" the situation. The user ought to participate as this is being done in order to ensure that the model truly describes the situation.

Presentation. The best analysis in the world does no good if it is not presented clearly and persuasively. Presentation deserves much thought and attention if the client is going to be persuaded to act on it.

Sometimes this process is cyclical or even done in another order. No matter what the sequence, success depends on how well each step is carried out and how closely the client is involved throughout. Military models *assist* in decision making. As pointed out earlier, most models do not provide a definitive answer but compare alternative choices according to an MOE. Four major modeling techniques to fit a particular situation are available (Figure 6):

- Analytical representations,
- Computer simulations,
- Arrangement of war gaming tools and personnel,
- Field experiments.

The pros and cons of each technique and may be found in *Military Modeling*, pages 1 - 36 found in the Readings for Chapter II.

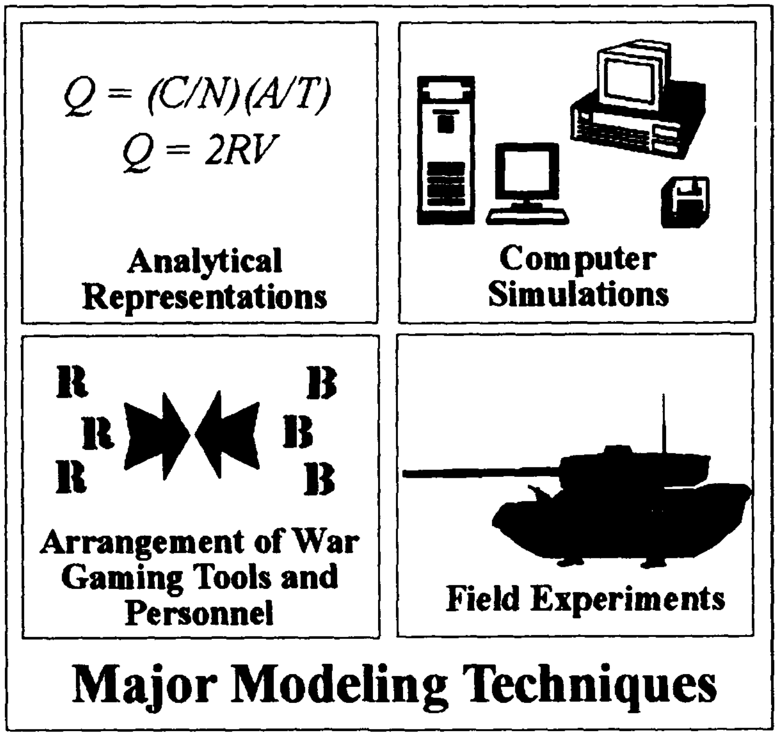


Figure 6

Some examples of model types listed for military applications include: models by application or purpose (battle planning, wartime operations, weapon procurement, force sizing, etc.), models by scope or scale (micro or single unit engagement models, multi-engagement models), ad hoc and standing models, and models that describe, prescribe or predict.

The use of all the above techniques, when applied to military operations analysis, has added a scientific grounding for making command and control decisions. This course will aid in the understanding of how modeling and analysis aid in making better command and control decisions, toward increasing our combat power and diminishing that of the enemy.

E. COMBAT MODELING AS A TOOL FOR COMMAND-CONTROL

Having defined the terminology associated with combat, command-control, and modeling, the next step is to discuss how they interact with each other.

As stated above, command generates maximum combat potential and command-control transforms combat potential into combat power. Making decisions that will increase either the combat potential or combat power of a force involves some sort of analysis. The analysis techniques and tools used vary from situation to situation.

As an example, consider the following case. A fleet commander embarked on a flagship must decide how to assign ships in the fleet to various tasks (i.e., functions) while steaming to battle. During the oceanic transit, surveillance is of utmost concern to the admiral. The admiral is faced with deciding how he will allocate aircraft between being combat ready and providing surveillance and scouting.

In this example, the system to be modeled is the battle group containing the aircraft carriers, battleships and support ships. Inputs to the system include: available aircraft of different types, fuel availability, pilots available and non-organic surveillance data including remote sensors, satellites, etc., as resources. In addition to the resources available, other inputs are present, including rules of engagement (ROE) and directions from higher authority requiring the admiral to remain undetected during the transit. The output from the combat model analysis should help determine the surveillance and strike aircraft based upon the surveillance information gathered.

The admiral must decide what his choices are, what tradeoffs exist, and what the values should be for the measure of effectiveness for this situation. Using a

certain aircraft for surveillance means that the aircraft is not available for a strike if it should be required. For his MOE, the admiral chooses to base his decisions on his ability to provide "sufficient" surveillance while retaining "sufficient" strike power.

The role of combat analysis is now to simulate the battle group with a highly specialized model, which the admiral can use to change the number of aircraft used for surveillance, as well as their search plan (radial and circumferential coverage), and see the resulting probability of detecting air, surface and subsurface attackers. At the same time, he has a strike plan, derived from analysis, which tells him how many aircraft will be necessary to attack a variety of targets. The combat modeler must be familiar with the interrelationships between all the input variables in order to provide an accurate model for the admiral. The admiral still retains full responsibility for a final judgment and decision.

The ability to determine these interrelationships requires experience not normally found in business or other type modeling. Due to the very nature of combat, specialists in the field of combat analysis must be used who are familiar with the various relationships that exist and the "laws" governing these relationships. This is the art of combat analysis and the trait that those in a position of command seek out to help them make decisions unique to the military environment.

The goal of this course is to provide the student with a background in the understanding of these combat modeling tools and techniques and an ability to work with the analysts who provide useful information to the commander. In order to do that, we have examined the functions of command and the processes of command-control and command-control countermeasures; how they affect combat

power and combat potential, how they are modeled and their usefulness. However, the terms and definitions which have been presented thus far are by no means the only ones associated with C^3 today. In recent documents, the concept of Information Warfare has been developed in order give credit to the enormous potential and power of communications, intelligence and computer systems in modern warfare. The *problem* with the documents is that Information Warfare, and related terms such as SEW, C^2W, C^4I and the C^4I for the Warrior Concept, has different connotations depending upon its use and whoever is using it. The term has been applied to various concepts, organizations, programs, structures or doctrine. We make no effort here to correlate the terms with our definitions of command and command-control, given the different connotations and malleability of the terms depending upon the issuing agency. We will, however, provide the student with a *sense* of how many military commands express their use of intelligence, computers and communications equipment in combat, in the following section on Information Warfare. This is only a short introduction. Additional discussions will follow throughout the C^3 curriculum.

F. INFORMATION WARFARE

If one accepts the argument that man has moved from the "Industrial Age" into the "Information Age" then one must acknowledge the importance of Information Warfare (IW) on the battlefield. Just as air superiority/supremacy became more and more critical to successful military operations during the "Industrial Age," information superiority/supremacy arguably has become just as, if not more, broad and important in the "Information Age" (AFSC, 1993, pg. 1.6). While air warfare meant the destruction of enemy air, ground and naval forces and

the protection of friendly ones using airborne assets, Information Warfare takes on more meaning. Not only does it involve the physical destruction of enemy air, ground, and naval forces and protection of friendly ones using information assets, it is also a tool used for attacking, confusing and misleading enemy C^2 centers and C^3 systems, while protecting friendly C^3 assets and assisting C^2 decision makers. Information Warfare gains on the battlefield, such as confusion of enemy commanders, misdirection of forces, or destruction of C^3 nodes, may be more difficult to see than physical bomb damage or territory taken from the enemy, nonetheless, these gains are just as important. Enemy confusion at both the command and tactical levels is a powerful weapon and one that can be obtained by using information as a tool of war.

1. Command and Control Warfare

The concept of Information Warfare is implemented on the battlefield through the use of the military *strategy* of Command and Control Warfare (C^2W). C^2W as defined by the Chairman of the Joint Chiefs of Staff in "Memorandum of Policy, Number 30," 1993, is:

> the integrated use of operations security (OPSEC), military deception, psychological operations (PSYOP), electronic warfare (EW) and physical destruction, mutually supported by intelligence, to deny information to, influence, degrade or destroy adversary C^2 capabilities, while protecting friendly C^2 capabilities against such actions" (CJCS, 1993, pg. 2).

C^2W has two divisions: C^2-Protection and Counter-C^2. C^2-Protection is a defensive action involving maintaining effectiveness of friendly C^2 by either enhancement of it or negation or destruction of enemy efforts against it. Counter-C^2 is an offensive action involving the prevention of enemy C^2 by denying information to, influencing, degrading or destroying the enemy's C^2 systems. Both

divisions employ all of the five principal military actions of C^2W, as seen in Figure 7 (CJCS, 1993, pg. 2).

COMMAND AND CONTROL WARFARE	
Counter-C^2	C^2-Protection
OPSEC	OPSEC
Military Deception	Military Deception
PSYOP	PSYOP
EW	EW
Physical Destruction	Physical Destruction

Figure 7

Operations security is the process of denying the enemy *information* about friendly capabilities and intentions by identifying, controlling and protecting the *indicators* associated with planning and conducting military operations (AFSC, 1993, pg. 9.2). Indicators may be physical, technical or administrative in nature. The key to OPSEC is that it not a stand-alone process. In order to be most effective it must be coupled with military deception.

Military deception is used to mislead enemy commanders so that they act or fail to act in a manner prejudicial to their own interests and advantageous to friendly forces. The deception must be believable, verifiable, consistent and simple in order to work. Ideally, it should reinforce the enemy's own prejudices and perceptions. On the other hand, we must be aware that the enemy is capable of deception too, and thus be alert to his efforts at, or possibilities of, deception.

When deception and OPSEC are combined together effectively, the enemy commander not only does not know of the true friendly-force plan, he also wrongly believes in the plan devised by friendly forces for his deception.

Psychological operations differ from deception in that they constitute a planned, systematic process of conveying messages to, and influencing, a selected group in order to establish and reinforce enemy perceptions of friendly military superiority. (AFSC, 1993, pg. 12.2). PSYOP can be used *cohesively*, to join a group to unite or look favorably on the friendly forces, or *devisively*, to separate a group from a particular leader or faction, or in combination with one another.

Electronic warfare can be viewed as the use of electromagnetic energy to attack an enemy's combat capability, to protect friendly combat capabilities against enemy electromagnetic attack, or surveillance of the electromagnetic spectrum for threat recognition. With the relatively recent proliferation of electronic means of communication and detection, EW can be a powerful tool for the commander.

Physical destruction can be thought of as either the complete destruction of a C^2 capability or system or as rendering it incapable for a given period of time. Destruction does not necessarily have to be physical in nature; if the enemy's C^2 abilities are removed yet the physical structures remain, the goal has been achieved.

Each of these actions, when taken separately, can have a measurable effect on the enemy. However, combat power is maximized when all five actions are coordinated as one. It is this integrated employment that is the essence and aim of C^2W strategy: an effective, efficient, coordinated application of different

capabilities, processes, techniques and weapons across the spectrum of an adversary's C^2 (CJCS, 1993, pg. 5).

2. Space and Electronic Warfare

In 1989, the Chief of Naval Operations formally designated Space and Electronic Warfare (SEW) as a composite warfare area and the Navy's *strategic* precursor to C^2W. The strategic objective of SEW is similar to that of C^2W: to separate the enemy commander from his forces, to render the leader remote from his people (to take command of his forces in effect), and control his use of the electromagnetic spectra. The target set consists of those systems, which when destroyed, yield this objective (CNO, 1992, pg. 1).

SEW includes both warfare and warfare support functions. As a warfare function, SEW is the destruction or neutralization of enemy SEW targets. As warfare support function, it is the enhancement of friendly force battle management through the integrated employment and exploitation of the electromagnetic spectra and the medium of space (CNO, 1992, pg. 2). These correspond to the C^2W divisions of Counter-C^2 and C^2-Protection. However *Space* is the key to differentiating SEW and C^2W. Because naval forces traditionally operate long distances from their bases of command and support, SEW is specifically designed for the use of satellite assets as warfare aids.

The warfare and warfare support functions of SEW include several disciplines designed to accomplish the functions (CNO, 1992, pp. 4-5). Figure 8 lists them.

SPACE AND ELECTRONIC WARFARE	
Warfare	Warfare Support
Operational Deception	Operational Security
Counter-Surveillance	Surveillance
Counter-C^4I	C^4I
Electronic Combat	Signals Management

Figure 8

At first glance, SEW and C^2W may appear to be mirror images of one another. However there are a few dissimilarities. For instance, while OPSEC and deception appear in both warfare systems, they are not linked to one another as closely as in C^2W. C^4I is a new term which will be defined later. Finally, PSYOP and physical destruction are not included in SEW. This does not mean that they are not involved in SEW at any level. PSYOP is difficult to achieve for ships at sea operating against one another. And while destruction is not specifically mentioned at this level, it is specifically included as a means towards achieving the goal of warfare.

3. Command, Control, Communications, Computers and Intelligence

Command, Control, Communications, Computers and Intelligence (C^4I) is the means to the end of Command and Control. It is self-described as the technological, organizational and doctrinal *system* that provides three functions: the delegation of forces (i.e., command and control), information management (i.e., communications and computers) and intelligence dissemination (CNO, 1992, pg. 5). For C^4I to accomplish those functions, it is to afford timely decision

making, provide horizontal and vertical C^2 interoperability, be available on demand, utilize global C^4I assets and be adaptive to unforeseen situations. Ideally, C^4I should be invisible to the commander, always available, working trouble free. C^4I can be thought of as the technical, technological means of assisting the commander in effective C^2 on the battlefield.

C^4I for the Warrior, promulgated by the Joint Chiefs of Staff in "C^4I for the Warrior, Objective Concept," began after Desert Storm. It expresses itself as a *concept* for a uniform-action infrastructure which will eventually tie together global C^4I assets in order to give the commander access to all required/requested information and will provide the information when, where and how he wants it. C^4I for the Warrior Concept differs from the C^4I warfare in that the latter is a "narrow" method of achieving gains on the battlefield and, as such, its entire scope is purely combat/conflict oriented. C^4I for the Warrior Concept, on the other hand, envelopes more than a battlefield, or a specific conflict. It is a global architecture for data, communications and intelligence updating, encompassing situations and operations both in peacetime and in war. However, that wartime connectivity, rehearsed by means of peacetime operations will make it an effective tool for SEW, C^2W and Information Warfare. It will provide the communications/intelligence link that assists SEW and C^2W commanders in fighting the Information War.

G. RELEVANCE TO FURTHER CURRICULUM COURSES

This chapter, more than any other, lays out the basic structure for the understanding of command and control as an entity. The basic terms, such as command, command-control, combat modeling and analysis, combat functions and

potential, etc., are essential for an understanding of the Command, Control and Communications concept as a whole. The terms defined within this chapter are used and referred to throughout the C^3 curriculum courses.

In CC 3000, Introducuon to Command, Control and Communications, C^3 was presented in a historical framework. Examples from current military structures were provided in order to acquaint the student with how command and control functions in the real world and how it has played a role in past military campaigns and operations. In the current course, C^3 is examined in a more fundamental framework. Here, the student strives to separate the historical accounts of the commander's abilities and experience from the commander's knowledge of C^3 as a concept. The purpose is to try to give the student a knowledge of the basic structure of combat and modeling techniques so that he/she will be able to evaluate and sometimes use similar models for him/herself.

In OS 3008, Analytical Planning Methodology, the terms of C^3 thus far presented, such as: forces, combat potential, combat power, etc., are used with actual military modeling applications. Through the use of mathematical and statistical design models, the student is shown how careful study of forces, combat potential, systems and processes aids in determining the proper mix of men and materials to accomplish military tasks. In OS 3603, Simulation and Wargaming, the student is shown how C^3 relates to actual wargaming and simulation scenarios, with the emphasis on using proven military models and creating ones that are mission specific.

The remaining CC courses: CC 4001, C^3 System Engineering, CC 4003, C^3 Systems Evaluation, CC 4750, Military C^3 Systems Issues and CC 4913, Policies and Problems in C^3, all use the concepts in Chapter II. However these courses

deal much more with concepts presented in later chapters and will be further expanded upon in those chapters.

H. REVIEW QUESTIONS

1. Distinguish between a function and a process as it relates to combat.

2. Define the terms command, command-control, and command and control system.

3. Identify the elements of a command-control system. What is an element's "state"? Explain why a surveillance system should not be considered as a component of the command and control system.

4. Describe the significance of the three components of the "element-action-element" model of combat. How are the two elements related? Is this a model of a process or a function?

5. Is it possible to measure combat force directly? Identify two alternate methods of measuring combat force.

6. Explain the difference between designed combat potential and available combat potential. Give several factors which may account for differences between the two potentials.

7. The fundamental equation of combat power defines combat power as a function of tasks (actions) to be performed and units (elements) to perform those tasks. How does command-control enter into this function and what are the effects of command-control on achieved combat power?

8. You have been told that command-control countermeasures is a process. Illustrate with three examples.

9. Describe the concept of Information Warfare and its relation to SEW, C^4I, and the C^4I for the Warrior concept.

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III. MODELING

AIM:

Provide the student with an understanding of the various types of models and their characteristics. Emphasize that a model is a tool for analysis. Discuss the role of the modeler in useful analysis, and analysis in aiding the decision maker.

OBJECTIVES:

- Definition of a model
- Purpose of modeling is to support decision making to improve performance and make better decisions
- Discuss the general uses of models -- as a decision aid, research tool, and a training device
- Understand characteristics of a good model
- Discuss types of models
- Discuss the modeling process
- Discuss the factors affecting model validity -- faulty data, faulty model and faulty reasoning or logic
- Emphasize the limitations of models
    - Distinguish between approximation and abstraction
    - All models are IF-THEN statements
- Discuss methods and consequences of data collection
    - Understand the effect of the wartime setting on data collection
    - Definition of "dirty data"

- Discuss the principles of proper model design
  - Emulate the physical phenomenon
  - Keep the model simple, yet adequate (apply reasonableness test)
  - Keep decision to be made in view -- ensure model assists the decision

READINGS:

1. Hughes, Wayne, Jr. *Military Modeling*, pp. 1-43, 1989.

2. Levis, Alexander, *Modeling and Measuring Effectiveness of C^3 Systems*, pp. 15-18, 1986.

3. Giordano and Weir, *A First Course in Mathematical Modeling*, pp. 29-40, 1985.

A. DEFINITIONS AND PURPOSE OF MODELING

"A model is a simplified representation of the entity it imitates or simulates" (Hughes, 1989, pg. 1). The goal of modeling is to strip away the superfluous detail and complexity of reality and lay bare the underlying variables, constants and relationships in order to draw conclusions, make predictions or support decision making. Specifically, the aim of military modeling is the study of combat forces to support decision making relevant to force structure and force employment. The purpose of military modeling, and modeling in general, is to provide a more solid basis for decision making with the goal of improving performance and the quality and timeliness of decisions made. "A model is useful if a better decision can be made with the information that it adds" (Hughes, 1989, pg. 17).

B. USE OF MODELS

Three fundamental uses of military models are as decision aids, research tools, and training devices. The principal application of these tools deals with the following force structure concerns (Hughes, 1989, pp. 23-33):

- Battle Planning -- to improve tactics, operations or force composition.
- Wartime Operations -- to solve time-sensitive questions.
- Weapon Procurement -- to apply principles of systems analysis to yield cost-effective selection of competing weapon systems.
- Force Sizing -- to help determine force mix, identity or establish trends, or project future requirements.
- Human Resources Planning -- to support management decision making primarily in the area of manpower personnel and training.

- Logistics Planning -- to project logistics requirements and optimize logistics support.
- National Policy Analysis -- to assess the impact of broader policy decisions on military concerns.

Since models are used to support decision making, their utility is most beneficial when they accomplish one or more of the following (Hughes, 1989, pg. 14):

- explore issues in an orderly way,
- structure and discipline the debate,
- compare and contrast alternatives,
- reveal new characteristics,
- lead to unexpected but valid conclusions.

C. CHARACTERISTICS OF GOOD MODELS

The principal measure of a model's usefulness is its ability to communicate the attributes of the phenomenon under study. The ability to communicate is constrained by several characteristics, the foremost of which are transparency, flexibility, and reproducibility (Hughes, 1989, pg. 24). Transparency refers to the ease with which the intended user can understand the model and its results. Simplicity and transparency both facilitate model modification. Flexibility refers to the ease with which a model can be adapted to varying situations, as well as wide ranges of input data. Reproducibility refers to the ability of a model to generate the same results using the same data each time the model is applied. Additionally, the results must be independent of the individual that applies the model. *Military Modeling* lists a total of 14 characteristics of military models based on findings of the Army Models Review Committee (AMRC) (Hughes,

1989, pg. 7). However these three, flexibility, transparency and reproducibility, together with relevancy (roughly, how much insight is enough) provide a framework for measuring a model's utility and validity.

Though credibility is a characteristic unto itself, according to the AMRC, Alexander Levis sets it in the forefront of model evaluation issues (Levis, 1986, pg. 15). Levis holds that the credibility of a model is a function of its coherence, corresponding clarity and workability. These functions address the extent to which the model's outputs agree with the anticipated outcomes, and the ease with which the model communicates the problem analysis. The ultimate test of a model's credibility is the willingness of the decision maker to apply the results of the model.

D. THE ANALYSIS AND MODELING PROCESS

The fundamental methodology of model development closely follows the classical approach to scientific problem solving. One approach to this methodology is described by Clayton Thomas {in (Hughes, 1989, pg. 56)} where he discusses the findings of Robert Dorfman, who recall, divides the analysis process into five stages:

- Perception -- recognition that a problem exists and the generation of a problem statement in the form of a measure of effectiveness.
- Formulation -- determination of what is to be measured and the generation of a hypothesis, frequently expressed as a model.
- Observation -- collection of data upon which to validate the model or generate conclusions.
- Analysis -- test the hypothesis against the observed data.

- Presentation -- recommendation of a course of action or decision based upon analysis of data and hypothesis.

A similar approach to modeling is given by Frank Giordano and Maurice Weir (Giordano and Weir, 1985, pp. 29-40) where the generation of an acceptable model is the result of an iterative application of the following steps:

- Identify the problem,
- Make assumptions -- determine variables, constants and relationships,
- Interpret the model -- state in concise terms,
- Verify the model -- check reasonableness and validity of results,
- Implement the model,
- Maintain the model.

The heart of modeling lies with the correct identification of the problem or situation to be studied and the correct identification of the more significant variables and the relationships between them. "The great art of modeling is to identify the primary relationships pertinent to the issue, isolate them, and study their effects" (Hughes, 1989, pg. 13).

E. FACTORS AFFECTING MODEL VALIDITY

Three principal factors which may cause a model to be invalid are faulty reasoning or logic, a faulty model, or faulty data.

<u>Faulty reasoning or logic</u> results from incorrectly identifying the problem to be studied or omitting significant variables pertinent to the problem. The modeler's judgment and expertise are critical to successful model generation

(Hughes, 1989, pg. 33). Hughes holds that combat modeling must be accomplished by professionals.

F. UNDERSTANDING THE LIMITATIONS OF MODELS

A faulty model results from the failure to identify the correct objective (measurement standard) for a given problem statement. See Morse and Kimball's analysis (pp. 52-53) of anti-aircraft guns on merchant ships as an example. Secondly, because models are based on limiting assumptions, they become IF-THEN statements (Hughes, 1989, p. 26). This means that if, and only if, the model and its data are correct, then the model results are true. Third, when the model is used outside the bounds of its limiting assumptions, the results must be suspect.

A fourth factor in model validity arises from approximation and abstraction. *Military Modeling differentiates between these two notions and identifies their* impact on model validity (Hughes, 1989, pg. 40). At best, models only partly and incorrectly represent reality. Their accuracy is a function of model fidelity. Additionally, "error" due to mathematical calculations, according to Giordano and Weir, can be attributed to round-off error (computer induced), and truncation error (a finite representation of an infinite series of terms) (Giordano and Weir, 1985, pg. 89). These "computational errors" are what *Military Modeling* more aptly calls approximations (Hughes, 1989. pg. 42). Abstraction errors are the result of limiting the complexity of the real situation so that it can be modeled. Thus, factors which only affect the situation in a secondary way may be omitted from the model in order to keep the model understandable and workable. Giordano and Weir term this phenomenon as "formulative error."

In many cases, the abstraction is deliberate because the analyst views the additional "error" as acceptable. Linear programming is an example of a powerful optimization technique that assumes that linear relationships always exist between variables; this is always a chancy assumption when modeling the real world, but it is good enough in many circumstances.

G. DATA COLLECTION

Faulty data may affect the model in several ways. First, if inaccurate data is used to generate the model, then the assumption made regarding relationships between variables, based upon the sample data, may be inaccurate. Secondly, if inaccurate data is used to verify or validate a model, then the model may be erroneously certified but, when it is used with more accurate data, it may generate faulty results. Giordano and Weir term the limitation on model accuracy as "measurement errors" (*Giordano and Weir*, 1985, pg. 89).

Wartime data collected to support combat analysis is especially susceptible to measurement errors due to the very nature of combat. Use of cover, concealment and deception result in inaccuracies in measuring enemy performance. The tempo of battle results in poor measurement and recording of friendly losses. Additionally, environmental factors may preclude measurements. Thus, wartime data must be viewed with skepticism. Because of the nature of this dirty data, Morse and Kimball argued for making changes in tactics only when at least a three-fold net increase (a hemibel difference) in performance could be anticipated (Morse and Kimball, 1946, pg. 38).

The importance of data in model accuracy is highlighted by Alfred Lieberman in an analysis of national policy modeling {in (Hughes, 1989, pg. 215-

233)}. He holds that discrepancies between model results are typically due to differences in input data or assumptions.

H. PROPER MODEL SELECTION

The final selection or generation of a model is governed by three simple principles:

- Keep the decision maker and the decision to be made in mind. The keys are timeliness and understandability.
- Keep the model as simple as possible, yet sufficient in detail to adequately reflect the environment being analyzed. According to Weir, the model must be reasonable, that is, "does it agree with common sense?"
- The model must emulate the physical phenomena being analyzed. Personal perceptions or biases introduced by either the decision maker or the analyst will hinder the model's validity.

I. RELEVANCE TO FURTHER CURRICULUM COURSES

In this chapter, modeling's characteristics, uses and selection are explored. Modeling is essential to the C^3 planner, in that it provides a basis for understanding how equipment and procedures interact before they are actually employed on the battlefield. Modeling helps describe the situation and gives planners and commanders alike valuable tools to use in order to try to achieve victory.

Several courses in the curriculum further explore modeling and modeling techniques. Many of their concepts and modeling procedures are built upon the premises presented in this chapter. OS 3008, Analytical Planning Methodology and OS 3603, Simulation and Wargaming, both deal primarily with modeling, while CC 4003, C^3 Systems Evaluation, applies statistical evaluation techniques to

examine various military C^3 models. In OS 3008, the basic structure of military modeling is examined with special emphasis on model development application and validation/verification. Resource allocation, constrained optimization and game theory will receive close attention. OS 3008 uses commercial computer software to explore various concepts and acquaint the student with actual modeling and analysis techniques. In OS 3603, the emphasis is more towards the technical applications of military models and modeling. Detailed model structure, computer coding of simulation models, random number generation, data analysis, sample size and replication of data, are presented. Additionally, students will learn to design their own models and work on actual military models (simulations and wargames) in use. Finally, in CC 4003, C^3 Systems Evaluation, models currently in use at the Naval Postgraduate School and ones in use throughout the military are examined and evaluated using statistical methods. These three courses extend and amplify the concepts introduced in this and later chapters.

J. REVIEW QUESTIONS

1. Define modeling and state its purpose.

2. Identify the fundamental uses of modeling.

3. Distinguish between the five different types of models as defined in *Military Modeling* and give an example for each category.

4. Give several ways in which models can be used to support decision making.

5. Given that the ability of a model to communicate provides a measure of its usefulness, explain why the model's transparency, flexibility, and reproducibility can affect its value. Explain why its fidelity can hinder its value.

6. Discuss the underlying importance of a model's credibility.

7. Compare and contrast the steps in an analysis as defined by Dorfman and Weir.

8. Identify the three factors which affect a model's validity, the stage(s) in the model development in which each is likely to occur, and measures which may be taken to mitigate their effects.

9. Distinguish between an abstraction and an approximation. give an example of when they might be desirable.

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IV. MEASURES OF EFFECTIVENESS, PERFORMANCE AND FORCE EFFECTIVENESS (MOE/MOP/MOFE)

AIM:

Define MOP, MOE and MOFE. Ensure the student understands the differences and similarities between variables and parameters in terms of equipment characteristics (or capabilities), system performance and operational (or organizational) effectiveness.

OBJECTIVES:

- Define Measures Of Effectiveness (MOE), Measures Of Performance (MOP) and Measures Of Force Effectiveness (MOFE)
- Show how the uses of MOEs are a logical consequence of modeling techniques to efforts geared towards improving the effectiveness of combat operations
- Show how the choice of MOE is dependent upon the phenomena being modeled -- either as a one-sided, force-on-force or hunter-evader model
- Examine analyses by Morse and Kimball during World War II showing how MOEs were developed based on the following concepts:
    - Sweep rates
    - Exchange rates
    - Comparative performance
    - Equipment performance evaluation

READINGS:

1. Rockower, Edward, "Notes on Measures of Effectiveness," pp. 1-6, 1985.

2. Sweet, et. al., "Command and Control Evolution Workshop," pp. 2.1-2.8, 1985.

3. Morse, Philip and George Kimball, *Methods of Operations Research*, Chapter 1, 3, 1946.

4. Thomas, Clayton "MOE's ... Origins, Evolution, Roles," pp. 1-13.

A. DEFINITION OF MOE/MOP/MOFE

Performance and effectiveness measurements provide a quantitative means of determining the extent to which mission requirements are being met, the degree to which a system is affecting the environment in which it is operating, or the impact an operational decision is having upon combat outcomes. In order to support better decision making, Edward Rockower asserts that one must "establish a consistent, quantitative, measurable and credible measure .. of the value of alternative courses of action .." (Rockower, 1985, pg. 2). These measures may assess the value of the system in terms of design specifications, functional operation or mission enhancement. According to Dr. Ricki Sweet, (Sweet, et. al, 1985, pp. 2.6) these measures are:

- Measures of Performance (MOP) -- a function of the system's behavioral attributes;
- Measures of Effectiveness (MOE) -- a function of the system's performance within the operational environment.
- Measure of Force Effectiveness (MOFE) -- a function of system effectiveness within a force structure in war.

B. IMPROVING EFFECTIVENESS OF COMBAT OPERATIONS

Morse and Kimball asserted that, prior to World War II, tactics and strategy were strongly influenced by environmental factors and little quantitative measurement of decision variables was possible (Morse and Kimball, 1946, pg. 2). They said that the principal purpose of Operations Research is to analyze tactics, strategy and equipment and the operations in which these are applied. Prior to the organization of the Operations Research Group (ORG) in April 1942, most scientific contributions to warfare advancement were in terms of new "gadgets"

vice better usage of current weapons (Morse and Kimball, 1946, pg. 1). The ORG supported:

- evaluation of new equipment, to include development of tactics to enhance their employment;
- evaluation of operations;
- evaluation and analysis of tactical problems;
- analysis of strategic planning;
- providing research and development liaison.

According to Morse and Kimball, the principal goal of Operations Research is to improve the efficiency (effectiveness) of current and future operations.

In "MOEs -- Origins, Evolution, Roles," Clayton Thomas identifies two principal uses for measures of effectiveness: as an indicator, to enhance the understanding of an operation or improve its performance; or as an optimizer, used to determine or select the best alternative. Thomas summarizes Omand Solandt's account of the use of MOEs in World War II as a three step process (Thomas, "MOEs -- Origins, Evolutions, Roles," pp. 4-5):

- Discover the purpose of the operations, i. e., describe it,
- Determine some means of measuring its effectiveness,
- Try to improve its effectiveness.

C. DEPENDENCE UPON PHENOMENA BEING MODELED

As one of their important contributions to analysis, Morse and Kimball introduced the use of MOEs for comparing the observed operations with theoretical outcomes, friend versus foe, exchange rates and operational results between different systems.

In striving to find the "constants of an operation" and determining how changes to them affect operations, Morse and Kimball demonstrate their use of MOEs in World War II analysis to be indicative in nature. Their goal was not to optimize combat operations, nor to predict the outcomes of battles, but rather to improve the use of tactics and equipment.

The selection of an MOE/MOP/MOFE is critical to performing a valid analysis of a system or operation. The choice of an MOE is often determined by examining the situation to be analyzed and the interaction of forces as either:

- <u>One-sided</u>: measures changes to situation due to actions of only one side. No response is considered by the opposing side. Most logistics (supply, medicine, repair) and many operations are of this nature.
- <u>Force-on-Force</u>: Participants on both sides in a conflict take opposing actions affecting the situation to be analyzed.
- <u>Hunter-Evader</u>: The aggressor takes action to discover or destroy his opponent, while the non-aggressor takes action to avoid detection. Much of Antisubmarine Warfare is of this nature.

A special case of the hunter-evader activity is the predator-prey situation, where the hunter seeks the evader with the intent of capture or destruction. In this case the prey (evader) has some means to fight back and inflict casualties on the hunter. An example of this case is the U-boat wolfpacks versus the armed convoys of World War II. Thus, these types of actions have some of the characteristics of the force-on-force case.

D. WORLD WAR II EXAMPLES

1. Sweep Rates

One of the first analyses examined by Morse and Kimball involved sweep rates. They suggested measuring the effectiveness of area searches by

comparing the operational values observed (Figure 9) to the theoretical values computed (Figure 10). The equations for these values are given by (Morse and Kimball, 1946, pg. 39):

C = number of contacts

N = probable number of enemy in area

A = total area being searched (square miles)

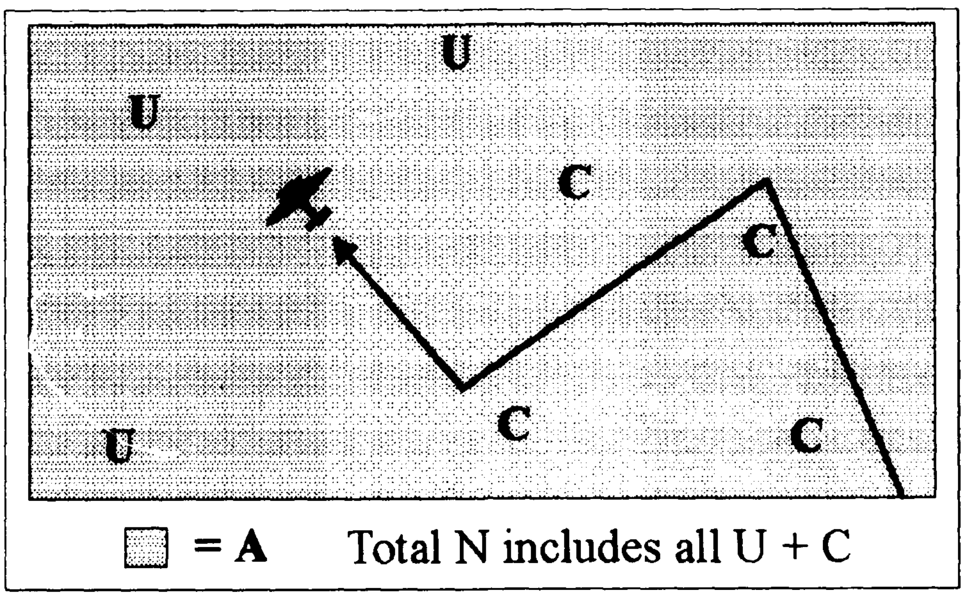
T = total search time (hours)

$\left(\frac{N}{A}\right)$ = the average density of enemy in the area $\left(\frac{\text{enemy}}{\text{square mile}}\right)$

$\left(\frac{C}{T}\right)$ = number of contacts produced per unit of search time (hours)

Q_{op} = operational sweep rate

$$Q_{op} = \frac{\left(\frac{C}{T}\right)}{\left(\frac{N}{A}\right)} = \left(\frac{C}{N}\right)\left(\frac{A}{T}\right) \text{ measured in square miles per hour}$$



Operational Sweep Rate Variables

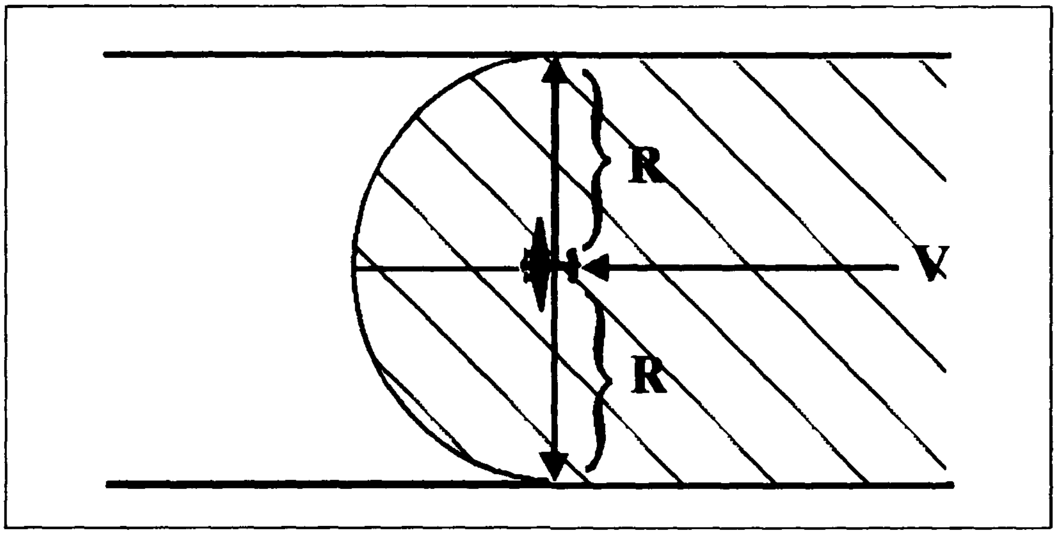
Figure 9

R = effective lateral range of detection in miles

V = relative speed of search craft in miles per hour

Q_{th} = theoretical sweep rate

$Q_{th} = 2\ R\ V$ measured in square miles per hour



Theoretical Sweep Rate Variables

Figure 10

Note that $\left(\frac{C}{N}\right)$ is the ratio of contacts made to the expected number of contacts in the area. If $\left(\frac{C}{N}\right) > 1$, then some of the enemy were contacted more than once. If $\left(\frac{C}{N}\right) < 1$, then some of the enemy were not contacted at all.

By taking the ratio $\frac{Q_{op}}{Q_{th}}$, a dimensionless factor results, giving the net effectiveness of the search activity. Q_{op} was generally less than Q_{th}. Morse and Kimball said this was to be expected, but when the operational rate was more a

factor of three less than the theoretical rate, then this was cause for investigation. (A factor of three was called a "hemibel" by Morse and Kimball. See page 46.)

Sweep rates may be used when measuring one-sided search activities or hunter-evader activities where the evasion tactics of the non-aggressor serve to limit the effectiveness of the aggressor's search. When the evader (prey) takes action to fight back and destroy the aggressor, exchange rates should be considered in addition to sweep rates.

2. Exchange Rates

A much-used MOE for all forms of warfare is the exchange rate, the ratio between enemy loss and own loss (Morse and Kimball, 1946, pg. 45). Assuming similar equipment on both sides, the exchange rate is simply:

l = number of enemy losses

k = number of friendly losses

$$\left(\frac{l}{k}\right) = \text{Exchange Rate}$$

The ratio of units lost to units engaged are:

m = number of friendly units engaged

n = number of enemy units engaged

$$\left(\frac{k}{m}\right) \text{ and } \left(\frac{l}{n}\right)$$

The ratio $\left(\frac{k}{m}\right) \div \left(\frac{1}{n}\right)$ is called the Fractional Exchange Ratio (among several names given it) and is one of the most useful measures of success in force-on-force situations. It will be examined in detail later in the course.

Factors affecting exchange rates that are not explicitly part of the equation include the training and experience levels of the participants and the types of equipment included in the engagement.

When high value targets, such as military convoys, are being pursued by aggressors, such as submarines, two important effectiveness measures are <u>encounter</u> and <u>engagement</u> rates. When the high value targets are protected by active friendly forces, sometimes an appropriate effectiveness measure is the exchange ratio, ships sunk to submarines sunk. Morse and Kimball examined the tactics of escorting convoys as an example of exchange rate measurements (Morse and Kimball, 1946, pg. 46).

3. Comparative Performance

Another MOE advanced by Morse and Kimball was to compare the relative effectiveness of different tactics or weapons. The difficult task here is to determine an equitable but usable unit of measurement. The analyst must determine what phenomena are critical and determine how these are affected by the various tactics or weapon systems being analyzed. As examples of the method of comparative effectiveness, Morse and Kimball analyzed the impact of anti-ship weapons on ship design and bombing of U-boat pens versus escorting convoys (whether the best use of aircraft in the protection of merchant shipping is as ASW platforms, interdiction, or close air support) (Morse and Kimball, 1946, pp. 48-49).

4. Analyzing Equipment Performance

Finally, Morse and Kimball showed how the MOE methodology could be applied to assess the performance of a weapon system. Four factors were identified which are relevant to measuring the effectiveness of a weapon system at any stage of its development (Morse and Kimball, 1946, pg. 52):

- Cost - "Is the new weapon system worth obtaining or using at all?"
- Employment - "When and where should the new system be used?"
- Maintainability - "Is the new equipment easy to maintain in operation?"
- Training - "How much and what type of training is needed in order for the new weapon to be more effective than the old one?"

Morse and Kimball cited the use of anti-aircraft guns on merchant ships, anti-torpedo nets, depth charge settings and supervised practice as examples of MOEs being used to assess new equipment's performance.

E. RELEVANCE TO FURTHER CURRICULUM COURSES

Performance and effectiveness measurement is desirable in any type of operation. However, in attempting to evaluate command, control and communication systems, it is nothing less than essential. A commander, a modeler, even a lone soldier, must have some way to discover the best alternative from a number of choices. This chapter introduces the student to various methods of determining the best MOE/MOP/MOFE. Additionally, equations for Sweep and Exchange Rates are presented in order to acquaint the student with how to numerically evaluate the optimum choice. This chapter provides an introduction to various examples and methods for measuring performance and effectiveness, a skill which will be much used in future courses.

OS 3008, Analytical Planning Methodology, uses MOEs and MOPs to introduce how operations researchers support planning decisions using various optimization techniques. Additionally, the student will use MOE development techniques to decide on appropriate measures for evaluating an assigned system. OS 3603, Simulation and Wargaming, teaches the student to make determinations of how to weigh choices given multiple MOEs with *different* measurement units using sensitivity analysis. This course uses the statistics and probability theory first introduced in OS 2103 and OS 3604 in order to provide hands-on MOE calculation experience. Finally, CC 4001, C^3 Systems Engineering, and CC 4003, C^3 Systems Evaluation, both use MOEs to explaining real world techniques and how actual military systems are designed, tested and evaluated utilizing appropriate measures.

F. REVIEW QUESTIONS

1. Distinguish between a measure of performance, a measure of effectiveness and a measure of force effectiveness. As these measurements are not mutually exclusive, give an example of a measurement which is both a measure of effectiveness and a measure of performance, depending on circumstances.

2. Distinguish between a force-on-force model and a hunter-evader model. Give an example of each. What is the impact on the model when an evader is able to retaliate and inflict injury upon the hunter?

3. Morse and Kimball, in World War II analysis, merely attempted to improve tactics and operations rather than optimize combat operations. Justify this approach.

4. Contrast the use of MOEs as indicators and optimizers.

5. Compare the three step process of MOE development on page 54 with *the methods of model generation* proposed by Giordano and Weir, In Section F of Chapter III.

6. a. Given that a scout plane has an average speed of 200 mph and can observe objects at a distance of 10 miles, what is its theoretical sweep rate?
   b. If the average density of enemy targets in the area of coverage is 0.0125 targets per square mile and the historical records indicate that the operational sweep rate is 65% of the theoretical, how many contacts can be expected in a 3 hour search?
   c. If the scout plane's effectiveness increases to 95% with a 25% reduction in speed, is the change warranted in terms of contacts made in a three hour period?
   d. How many contacts would have to be made in a three hour period to achieve an operational sweep rate of 100%?
   e. On what basis might the observed sweep rate actually exceed the theoretical sweep rate?

7. One of the decisions studied by Morse and Kimball was whether to install anti-aircraft guns on merchant ships. Identify two possible reasons for these installations and the MOE associated with each reason. Analyze the reasonableness of the installation in terms of the four factors given for evaluating equipment performance.

V. ATTRITION BASED MODELS

AIM:

Introduce the student to elementary force-on-force models. Introduce attrition models which rely solely on casualty data to determine outcome of the battle. Provide the students with attrition formulas as tools for early combat analysis, along with examples to ensure an understanding of the equations.

OBJECTIVES:

- Show that attrition models are based on simultaneous infliction of casualties
- Present the logic and conditions for Lanchester's Laws
    - The linear law equation
        - Discuss the concept and application of area fire
        - Discuss the alternative application - a series of duels
    - The square law equation
        - Discuss the concept and application of aimed fire and the mathematics of concentrated firepower
        - Present Hughes' approximation to the square law for engagements where losses are < 20%
        - Introduce analysis of Iwo Jima and other attempts at model validation
    - The mixed law equation
        - Discuss the application of mixed laws in modern combat
    - Limitations of Lanchester laws

- Present law of exponential decay in combat
  - Discuss application of law to self-attrition and examples of Guadalcanal and Napoleon's march to Moscow
  - Discuss Schneider's use of the exponential law and the significance of the effectiveness coefficient
- Provide the student with an opportunity to use laws in examples
- Communicate the limitations and applicability of attrition models
  - Discuss the idea of movement/suppression/domination vs. attrition
  - Discuss shock and mass and the need for treatment of "salvoes" or "pulses" of combat power
  - Surprise is hard to model

READINGS:

1. Washburn, "Lanchester Systems," pp. 1-10, 1985.
2. Lindsay, Glenn "Lanchester Equations," pp. 1-23, 1977.
3. Hughes, Wayne, Jr., "Straight-Lining Casualty Rates"
4. Schneider, James, *Exponential Decay of Armies in Battle*, pp. 100-126, 1985.

A. SIMULTANEOUS INFLICTION OF CASUALTIES

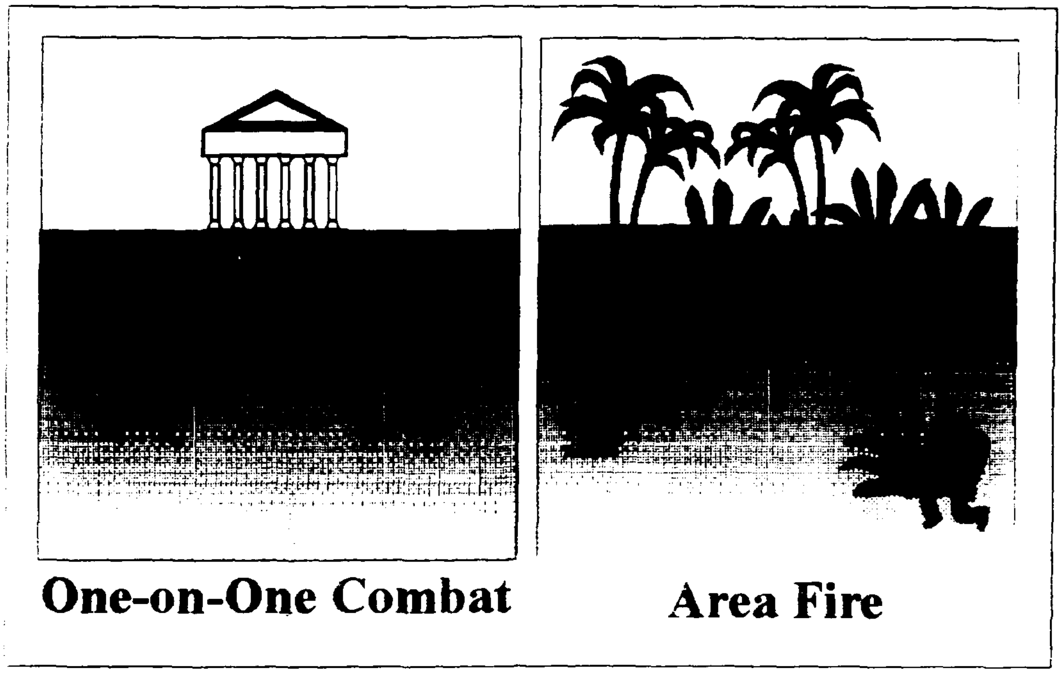
Early attempts at modeling the combat process used the attrition of forces as a measurement of effectiveness to describe or predict battle outcomes. Attrition modeling relates casualty rates to the number of forces on each side and their unit effectiveness. It solves equations describing casualty rates in order to provide a state equation which can be used to determine the remaining number of forces on each side at any given time.

B. LANCHESTER LAWS

Frederick Lanchester derived simple equations to account for battle outcomes based upon attrition rates. Each of his two equations can, in themselves, emulate two different combat situations (Lindsay, 1977, pg. 1).

1. Linear Law (Washburn, 1985, pg. 9; Lindsay, 1977, pp. 2-5)

This law models the effects of "ancient" one-on-one combat where a battle was a series of independent duels, each between exactly two combatants. As one combatant triumphed over one opponent, another would take his place until the succession of duels eventually left one side completely eliminated. The second combat situation this law can be applied to is the exchange of unaimed fire between forces where neither side can effectively target the other. In effect, each force is firing an "area fire" pattern in an effort to inflict casualties by random shots (Figure 11).



Linear Law Combat Situations

Figure 11

The rate of change form of the area fire linear law is:

(1) $$\frac{dB}{dt} = -\alpha_R BR\ ; \quad \frac{dR}{dt} = -\alpha_B RB$$

where:

	B	=	Blue Force strength
	R	=	Red force strength
	α_B	=	Effectiveness of B
	α_R	=	Effectiveness of R

These rate equations yield the state equation of the linear law as follows:

$$\frac{B_o - B_t}{R_o - R_t} = \frac{\alpha_R}{\alpha_B}$$

where: B_o, R_o = initial force strengths

B_t, R_t = force strengths at time t

The final result of the battle can be predetermined by examining the following ratios:

$$\frac{B_o}{R_o} \{ =, >, < \} \frac{\alpha_R}{\alpha_B} \qquad (2)$$

If: "=" then outcome is a draw

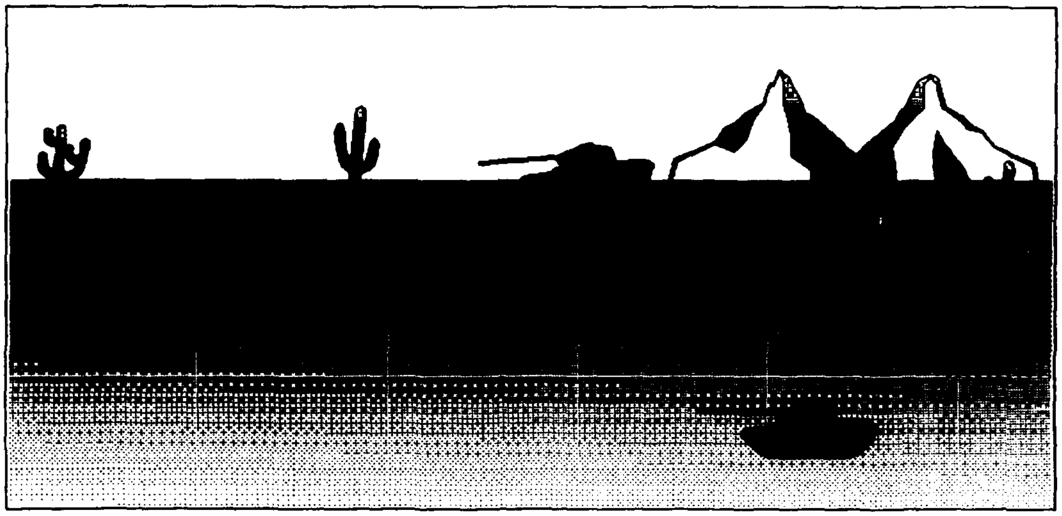
">" then blue will eliminate red

"<" then red will eliminate blue

2. Square Law (Washburn, 1985, pp. 6-9, Lindsay, 1977, pp. 6-7)

When either side is able to simultaneously concentrate his its fire upon the opponent (when one-on-one combat no longer applies) and is able to aim at any and all targets on the other side, then the linear law no longer emulates the combat. In this situation, the ability of forces to provide "aimed fire" at the enemy becomes significant and a new equation must be employed to account for the improved fire and infliction of casualties.

The name of the law is derived from the fact that the squares of the fighting strengths appear in the state equation. The significance of the model is the fact that the number of combatants engaged has greater influence on the outcome of the battle than the attrition effectiveness of individual combatants. The ability to aim fire at the enemy results in a squaring effect of the number of forces fighting in a battle (Figure 12).



Square Law Combat Situation

Figure 12

The rate of change form of the square law is:

$$(3) \qquad \frac{dB}{dt} = -\beta_R R \; ; \; \frac{dR}{dt} = -\beta_B B$$

where: B, R: represent force strength of Blue and Red

β_B, β_R: attrition effectiveness coefficients of Blue and Red

The rate equations yield the state equation of the square law:

$$(4) \qquad \frac{B_o^2 - B_t^2}{R_o^2 - R_t^2} = \frac{\beta_R}{\beta_B}$$

where: B_o, R_o: represent initial force strengths

B_t, R_t: force strengths at time t

The final result of the battle can be predetermined by examining the following ratios:

$$(5) \qquad \frac{B_o^2}{R_o^2} \{ =, >, < \} \frac{\beta_R}{\beta_B}$$

if: "=" then outcome is a draw

">" then blue will eliminate red

"<" then red will eliminate blue

3. Hughes' Approximation To The Square Law

While the Lanchester square law provides a straightforward means of determining force strength and outcome in a battle of annihilation, the fact is obscured that most of the square law advantage accrues to the winner towards the end of the battle. From history we know that average land battles will be broken off when casualties are less than 10%. Even in a major battle, casualties seldom exceed 30%. For battles when casualties are less than 20%, a linear approximation of the square law will serve. For equation (3), we substitute:

$$(6) \qquad \frac{\Delta B}{\Delta T} = \beta_R R_o \, ; \quad \frac{\Delta R}{\Delta T} = \beta_B B_o$$

where $\left(\frac{\Delta B}{\Delta T}\right)$ and $\left(\frac{\Delta R}{\Delta T}\right)$ are the *losses,* $B_o - B_t$ and $R_o - R_t$ respectively, after ΔT, which is now the *duration* of the battle. A comparison of the calculated outcome with the formal square law will demonstrate that the difference is negligible when casualties are low.

The corresponding state equation is:

$$(7) \qquad \frac{B_o - B_t}{R_o - R_t} = \frac{\beta_R R_o}{\beta_B B_o}$$

where: B_t, R_t : are the survivors of Blue and Red at time (t).

Simply stated, in the early stages of a battle in which aimed fire conditions hold, the ratio of blue losses to red losses is the inverse of the ratio of the product of their respective attrition coefficient and initial force strengths.

4. Mixed Laws (Lindsay, 1977, pg. 9)

S. J. Deitchman suggested using the combination of Lanchester's linear and square laws to model the outcome of a battle where only one force is able to concentrate or aim its fire (Lindsay, 1977, pg. 9). Typical applications of this type of mixed law include amphibious assaults, ambushes and guerrilla tactics. The attrition equations for this law where Blue ambushes Red are:

(8) $$\frac{dR}{dt} = -\beta_B B$$ (from the square law); and

(9) $$\frac{dB}{dt} = -\alpha_R BR$$ (from the linear law).

The resulting state equation is:

(10) $$\frac{B_o - B_t}{R_o^2 - R_t^2} = \frac{\alpha_R}{2\beta_B}$$

Assuming that Blue is able to continue the aimed fire and Red is unable to seek cover or transition to aimed fire, the outcome of the engagement may be predicted by:

(11) $$\frac{B_o}{R_o^2} \{ =, >, < \} \frac{\alpha_R}{2\beta_B}$$

where: "=" results in a draw

">" Blue wins

"<" Red wins

5. Limitations of Lanchester Laws

All of the Lanchester attrition equations presented have similar limitations. The fundamental difference between the linear and square law applications is the degree of control the commander is able to attain and maintain over his troops and the situation. In his discussion of the effects of suppression, James Schneider observes that "the square law .. assumes absolute and simultaneous projection of force upon a target. In land warfare, this projection is usually relative and only simultaneous at the decision point" (Schneider, 1985, pg. 88). This agrees with Hughes' assertion that combat is the functional, temporal and spatial application of force. Thus, the underlying assumption of Lanchester's square law, which requires that the concerted action of each combatant be controlled, is frequently unobtainable in actual combat. Any failure of control results in a breakdown not only in efficient targeting, which in effect degrades performance from aimed (concentrated) fire to area (individual) fire, but also reduces the ability or willingness of individual combatants to engage the enemy.

6. Solved Problems

Glenn F. Lindsay's article "Lanchester Equations" presents several exercises for understanding the Lanchester equations. Three of his problems are presented here with solutions so that the reader may see how the equations are used.

PROBLEM 1 (pg. 19):

Given: Initial Red Force strength: 100.

Initial Blue Force strength: 120.

Red and Blue use aimed fire with kill rate 0.1 and 0.08, respectively.

A. Determine the expected winner of a fight to the end.

$$\frac{B_o^2}{R_o^2} = \frac{14400}{10000} = 1.44$$

$$\frac{\beta_R}{\beta_B} = \frac{0.1}{0.08} = 1.25$$

Thus, $\frac{B_o^2}{R_o^2} > \frac{\beta_R}{\beta_B}$, which implies that Blue wins.

B. Determine the final strength of the winner.

$$\frac{B_o^2 - B_t^2}{R_o^2 - R_t^2} = \frac{\beta_R}{\beta_B},$$

$$\text{Thus, } \frac{14400 - B_t^2}{10000 - 0} = \frac{0.1}{0.08}.$$

$$\text{Therefore, } B_t^2 = 14400 - 10000(1.25) = 1900.$$

Hence, Blue survives with 43.58 troops left.

Note that this shows one of the limitations of the Lanchester model, in that it models a continuous loss curve with fractional outcomes, as opposed to a discrete step-loss curve.

C. Determine how many elements Red would have needed to achieve a victory.

$$\text{For Red to win requires: } \frac{B_o^2}{R_o^2} < \frac{\beta_R}{\beta_B}.$$

$$\text{Thus, } \frac{14400}{R_o^2} < \frac{0.1}{0.08}.$$

$$\text{Therefore, } R_o^2 > 14400(.8).$$

Hence, Red needs at least 108 elements to dominate Blue.

PROBLEM 2 (pg. 19):

Given: Red force ambushes Green; Red uses aimed fire, Green responds with area fire.

Initial Green strength: 150 men.

Initial Red strength: 25 men.

Red firing rate is 40 aimed shots per minute, with a single shot kill probability of 0.2.

Implies: Red attrition coefficient is (40)(0.2) = 8 kills/min.

Red is dispersed over 1000 square feet.

Area of each Red troop exposed: 0.2 square feet.

Green's probability of a kill against Red given a hit is 0.5.

A. Find the critical value for Green's rate of fire. That is, at what rate of fire by Green, does the outcome of the battle change?

$$\text{For parity, } \frac{R_o}{G_o^2} = \frac{\alpha_G}{2\beta_R}.$$

$$\text{Solve for, } \alpha_G = \frac{2 \times 8 \times 25}{(150)^2}.$$

$$\text{But, } \alpha_G = \frac{\{\text{rate fire}_G\}\{\text{exposed area}_R\}\{p(\text{kill given hit}_G)\}}{(\text{Red dispersal area})}.$$

$$\text{Solve for the Green rate of fire: } \frac{(2)(8)(25)(1000)}{(.2)(.5)(150)^2} = 177.8$$

Therefore, if Green maintains a firing rate of 178 shots per minute, Green will win. If Green's firing rate drops to 177, then Red will win.

B. Determine the effect of changes to Green's rate of fire (rate_G) on Red's residual strength, R_t (Assume Red victory).

$$R_t = R_o - \frac{\alpha_G(G_o^2)}{2\beta_R}.$$

$$\text{Thus, } R_t = 25 - \frac{\text{rate}_G(.2)(.5)(150)^2}{2(8)(1000)}.$$

In this equation R_t is inversely proportional to rate_G.

PROBLEM 4 (pg. 20):

Given: Combatants in wagon train: 50 men and women.

Indian combatants: 100 men.

Probability of a hit by wagon train members is three times that of the Indians.

Firing rates are equal for both sides.

Cavalry arrives when 25 wagon train combatants remain.

Arriving cavalry forces have the same rate of fire and hit probability as the Indians.

A. How many cavalry men need to be sent to defeat the Indians if the cavalry arrives when there were only 25 wagon train members left?

$$\frac{(W_o^2 - W_t^2)}{(I_o^2 - I_t^2)} = \frac{\beta_I}{\beta_w}; \quad \frac{(50^2 - 25^2)}{(100^2 - I_t^2)} = \frac{1}{3}$$

Solving for I_t gives the number of Indians remaining to be 66, so the number of cavalry men needed will be 67 (assuming the rate of fire and accuracy is the same for the cavalry as it is for the Indians).

B. If only 60 cavalry men are sent to assist the wagon train will there be any survivors of the wagon train party when all battles are completed?

Assuming the Indians focus all their attention on the cavalry first, then the number of Indians remaining after the cavalry is defeated is determined by:

$$\frac{\left(66^2 - I_t\right)^2}{\left(60^2 - 0\right)} = \frac{1}{1};$$

so $I_t = 28$ Indians remaining.

Next solve for the outcome of a battle between 28 Indians and 25 people in the wagon train:

$$\frac{\left(25^2\right)}{\left(28^2\right)} ? \frac{1}{3};$$

since 0.7972 > 0.333, the wagon train party will win.

The number of wagon train survivors is determined by:

$$\frac{\left(25^2 - W_t^2\right)}{\left(28^2 - 0\right)} = \frac{1}{3};$$

solving for W_t gives 19 wagon train survivors.

C. EXPONENTIAL LAW

When control (distribution and concentration of fire) diminishes, the probability increases that a given target receives more than one fatal or disabling hit, and the net effectiveness of the fire decreases. Moreover, as command, leadership and control over individual shooters diminishes, the ratio of firing elements to inactive elements also declines. Those elements not providing fire become mere "passive targets." In studying the works of BGen S.L.A. Marshall, Schneider observed that only 15-25% of a unit would fire their weapons, and even

then, not all of them would fire with any consistency or control (Schneider, 1985, pp. 100-107). He concluded that, when the limitations imposed upon combat operations by imperfect command and control and inactive shooters are taken into account, the linear law should be modified by dropping the factor reflecting the number of enemy shooters (Schneider, 1985, pp. 108-114). The resulting rate of change equations then become:

$$\frac{dB}{dt} = -\gamma_R B,$$

$$\frac{dR}{dt} = -\gamma_B R,$$

These equations imply that the loss of force is proportional to the size of the force. Thus, while Lanchester holds that superior numbers result in superior results, this model implies that a large force can expect greater losses than a small force. After integrating these rate equations, the resulting state equations are:

$$B_t = B_o \exp[-\gamma_R t]$$
$$R_t = R_o \exp[-\gamma_B t].$$

We do not have space to develop all of Schneider's rationale for this very counter-intuitive conclusion. Note the following however. First, Schneider's development is for ground combat. Second, the basis of his conclusion is from the empirical evidence of ground combat. He goes on to offer explanations for this strange data, but his theorizing (Schneider, 1985, pp. 108-126) is, unlike Lanchester, solely for the purpose of explaining what historians have observed in practice. Third, it should be remembered that the firing side is represented by the attrition coefficient, γ (gamma), and treating the coefficient as a constant is only an approximation, since the firing side's fire will diminish as it suffers losses. Even more important, the better trained, motivated and more numerous force will

have the larger attrition coefficient. We may summarize by saying, the exponential law asserts that loss rate to Red at any time during the battle will be directly proportional to an unchanging fire effectiveness of Blue and to the number of Red forces remaining at that time.

D. THE OPERATIONAL ART CONNECTION

This chapter is about combat rather than operations, but before concluding, passing mention should be made of another application of the exponential law. In a campaign of many weeks, losses from sickness have frequently exceeded losses from enemy action. Examples of this are the French losses in Napoleon's invasion of Russia and march to Moscow in 1812, and the US and Japanese losses in the campaign for Guadalcanal from August 1942 to January 1943. In these instances, the form of the loss equations is still exponential, but now the coefficients will represent the rate of incidence of sickness of one's own forces, and similarly represent the breakdown rate of tanks, aircraft and other vehicles.

E. THE COMMAND AND CONTROL CONNECTION

The fundamental difference between battles following the square law and those following the exponential law is the degree of control maintained by the commander over the situation. The closer command comes to bringing all its forces into action without massing them so that they are easily targeted, and the closer it comes to the ideal distribution of fire so that each shooter aims at a different live and threatening target, the closer it comes to square law performance. According to Schneider, "In land warfare Lanchester's square law is not the reality, it is the ideal; but an ideal that must always be striven for .. (which) is, at the heart, the spark of military genius" (Schneider, 1985, pg. 57).

To the extent that a command and control system enables the commander to direct and control the actions of his forces in combat and achieve square law effects, the system may be seen as a force multiplier. Where both forces have efficient command and control, the square law favors the side with superior numbers. Where both have inferior command and control, the linear law favors the force with better individual performance. Where both are massed so as to become easy targets for the enemy, the exponential law favors the smaller force.

F. LIMITATIONS OF ATTRITION MODELS

Attrition-based models only provide insight into the effects of fire upon remaining numerical strength. The ability to achieve the square law effects is limited by terrain, in the case of land warfare, and by the commander's ability to maintain control over his engaged forces. Three of the most prominent factors affecting his ability to control his forces are the fog of war, friction and suppression.

1. Fog of War, Friction and Suppression

The "fog of war" is the phenomenon of confusion that results when humans under intense stress try to make decisions and communicate them. Fog of war also implies uncertainty about the situation. In the lethal competition of combat, the pressure to act in a timely way forces decisions to be made with incomplete information. Several observers of military history have concluded that the fog, confusion, uncertainty and lack of knowledge in combat, will continue to occur unabated, despite all of the technological advances in scouting (information gathering) and new and powerful means of information transmission such as JTIDS (Joint Tactical Information Distribution System).

Friction comes in two forms. One is the effect of the environment, both terrain and weather. This is external friction. The other is the result of many forces trying and failing to act in a fully cooperative and coordinated way. The greater the number of forces, the greater the friction (inefficiency) that results; a fact which is well known and which has been quantified by Trevor Dupuy in *Understanding War*. This lack of fully coordinated action within a force is internal friction.

Suppression is the reduction of actions brought about by enemy lethal actions. Primary actions suppressed by enemy fire are own fire, movement, communication and logistics or resupply. Another activity suppressed by enemy action and not to be overlooked is the speed and quality of the decision making process itself. Suppression is a special case of what may be called "resistance," that is, all actions taken (naturally including weapon fire) to reduce the effective actions of the enemy.

The term Command and Control Warfare (C^2W) was introduced in Chapter II. C^2W uses any means at hand to (1) prevent effective C^2 of enemy forces by denying information to, influencing, degrading or destroying his C^2 process; and (2) maintain effective C^2 of own forces by negating enemy efforts to interfere with it. C^2W is a particular form of suppression of the enemy C^2 process and denial of suppression by the enemy of one's own C^2 process.

Insofar as this chapter is concerned, the thing to note is that fog of war, friction and suppression are not inherent in Lanchester equations and are only included indirectly (e.g., by degraded coefficients of unit effectiveness) if they are included at all.

2. Intelligence, Deception and Maneuver

Effective firepower requires the allocation of the proper weapon or force composition for a given objective. Thus, concentration is the result of applying the right forces at the right time and place. To reduce an opponent's ability to concentrate his combat power, a commander must apply his force in such a way as to frustrate the opponent's attempts to mass his firepower at the decisive place and time. This may be done in various ways, two of which are deception and scouting. Deception attempts to mask the position of one's forces, or confuse the enemy regarding one's intentions. The net effect is to cause doubt as to the actual decisive point. Scouting, on the other hand, attempts to locate the vital point at which the enemy should be struck.

Critical to massing firepower is maneuver. Freedom of movement on the battlefield helps to achieve and maintain concentration. Furthermore, denying the opponent freedom of movement ("the right forces at the right time and place") helps to achieve a square law advantage. The square law artificially assumes constant unit effectiveness and continuous attrition. This is only achieved when the enemy is fixed in place.

3. Pulsed Firepower and Surprise

The continuous nature of fire of the square law is contrary to the nature of much of modern warfare. As will be shown in the next chapter, about naval combat, the trend toward aircraft carrier based forces and the use of stand-off missiles has led to a pulsed delivery of firepower, where the combat power must be measured as the result after each pulse, rather than the continuous process modeled by Lanchester methods.

One final factor not yet discussed which greatly impacts the results is surprise, especially so when the firepower arrives in pulses. While its effect on morale and troop posturing cannot be disputed, an elementary firepower model can only presume that surprise occurs, but cannot investigate the processes by which surprise is actually achieved.

G. SUMMARY

The following points should be understood as a summary of the attrition modeling techniques developed in this chapter:

- The model form will vary according to the physical characteristics of the battles. There is no general model, and the analyst must apply the form that fits the conditions.

- Insight into the quantitative value of C^2 contributions may be seen by the way combat power is increased through coordinated (square law form) versus uncoordinated activities (linear or exponential laws).

H. RELEVANCE TO FURTHER CURRICULUM COURSES

In this chapter, the student is introduced to the attrition equations developed by Frederick Lanchester, along with other similar types of equations which model different forms of combat. The Lanchester laws, as they have come to be known, are used because they help our understanding of the value of numerical superiority. Without a means of quantifying and mathematically describing force-on-force encounters and their results, all military analysis would be based solely on historical evidence and war games. This would leave great room for inaccuracies due to personality influences. Every military computer model, every military wargame, utilizes some means of evaluating and describing the effects of

force encounters within its designed boundaries. Many of these models use Lanchester-like attrition models within them. Often, results of simulations and war games are represented solely by "killer-victim scoreboards" (which arms achieved the casualties against which enemy units). That is why the student must understand how these encounters are described and how they are evaluated.

Several courses utilize the equations themselves or base much of their content upon an understanding of how similar equations work. OS 3008, Analytical Planning Methodology and OS 3603, Simulation and Wargaming, both use the Lanchester laws and introduce other similar equations and techniques in order to demonstrate their course objectives. In OS 3008, detection models, mixed strategy formulations and search effectiveness functions are used in order to show how to optimize the allocation of resources. After examining the concepts through manual calculations, computer models employing commercial software are employed in order to speed up the work and provide experience for the student. In OS 3603, statistical evaluation techniques are employed in order to evaluate outcomes measured in casualties based on Lanchester laws and other similar force-on-force equations. In addition, the student begins to put the laws and equations to use within actual computer models, both in class and utilizing working military combat models. Finally, CC 4003, C^3 Systems Evaluation, examines how the models themselves work based upon the computer encoded equations.

I. REVIEW QUESTIONS

1. Differentiate between the classical Lanchester square law and Hughes' approximation to the square law. Which formula is more "technically" correct? What purpose or usefulness does the other equation provide?

2. What are the necessary conditions for the linear and square law to hold? What must be done if the necessary conditions do not hold?

3. Given that an individual (blue) shooter can fire at a rate of 5 rounds per minute, each opponent (gray) provides a target area of 0.165 square feet (6 in x 4 in) and the field of fire is 30,000 sq. ft (100 yds deep, 100 ft wide), calculate the individual effectiveness coefficient for the blue shooters if the field contains 50 gray troops, assuming that the enemy is providing sufficient suppressive fire to cause the shooters to only fire at a wide area sporadically.

4. Given that each blue shooter in the above question presents a 0.33 square foot target to the opponent and that each opponent is capable of placing his round in a 1 square foot area at the same rate, determine the single shot hit probability for the gray shooters. If the probability of a kill given a hit is 0.5, then determine the overall effectiveness coefficient for a typical gray shooter.

5. For problem 3, determine the initial blue troop level necessary to ensure a blue victory (at least one blue shooter remaining) in a fight to the death. Is it reasonable to assume that blue would continue the fight under these circumstances (Why or why not)?

6. Given that blue has less than the minimum number of troops necessary as determined by problem 4, name three measures which blue may take to increase his likelihood of a favorable outcome.

7. Assuming that blue is able to transition to aimed fire, has 100 troops remaining at the time of transition, each with the same rate of fire and probability of kill given a hit as a typical gray shooter, use Hughes' approximation to determine the resulting troop strengths, given that gray has only 40 troops remaining when the transition occurs and is willing to lose only 4 more men.

8. According to the linear and square laws, the effect of doubling one side's effectiveness coefficient is to double the rate of losses incurred by the other. Determine the effect of doubling the effectiveness coefficient on the exponential decay model. Which factor then has more significance in the final troop strength, initial troop level or the opponent's effectiveness?

9. As a consequence of Section F, Limitations of Attrition Models, why does it make sense to think of a command and control system as resulting in a force "diminisher" vice multiplier?

10. Discuss methods which a commander may take to limit the ability of his opponent to achieve square law effects.

11. Cohesion may be defined as spiritual bonding or morale within a force. Explain why force cohesion is important in battle. In your opinion, what was the benefit of drum and fife corps in battle?

12. Why is it important for shooters to return fire when pinned down?

VI. NAVY BATTLE MODELING

AIM:

Review naval combat in history to show that while force against force and attrition have been dominant in the nature of naval combat, their manifestation, and therefore the appropriate model of sea combat, has changed during four periods. The Lanchester (continuous fire) model has to be replaced in modern combat with a pulsed power model. Introduce tactical decision aids.

OBJECTIVES:

- Present five cornerstones of maritime warfare
- Distinguish the great trends from the constants of naval combat
- Discuss the functions (processes) of naval combat -- shooting, scouting, C^2 and their antitheses
- Look at the evolution of naval combat and effect on C^2 in terms of modeling of various force-on-force engagements:
    - The age of the fighting sail and the smooth bore gun (continuous fire between ships)
    - The age of steam and rifled gun (continuous fire between fleets)
    - The age of aircraft carriers (pulsed firepower)
    - The missile age
        - Review the modern naval force-on-force model in terms of missile attack and defense
- Emphasize that models of naval combat are attrition-based
    - "Scouting" must be included for complete understanding of C^2

- Examine the increasing role of tactical decision aids as used by the Navy

READINGS:

1. Hughes, Wayne, Jr., "Naval Pulsed Firepower Combat Model," 1988.

2. Snyder, Frank, *Command and Control: Readings and Commentary*, "Session 4 - Operational Decisions: Decision Aids," pp. 47-57, 1989.

REFERENCE:

1. Hughes, *Fleet Tactics: Theory and Practice*, Naval Institute Press, 1986.

A. BACKGROUND

At this point, the reader will recognize that Lanchester laws are simply tools which must be correctly chosen and applied to create a useful combat model. Formulas are only tools describing combat phenomena in a simplified, essential way. Effective combat modeling involves much more than a simple understanding of mathematical formulas and their applications.

By studying naval combat, the reader will be able to see how basic formulas can be applied to understand past naval warfare and to develop models describing naval combat for the future. The limitations of the laws discussed in the previous chapter indicate that there must be other tools to simulate the environments and situations not covered by the Lanchester laws. In order to create useful combat models, it is necessary to have a collection of tools other than just mathematical equations at your disposal. These other "tools" include: understanding the historical application of force in the type of warfare being analyzed (naval warfare in this case), and an understanding of the trends and constants observed through history. In his book, *Fleet Tactics: Theory and Practice*, CAPT. Wayne Hughes (USN Ret.) addresses the historical perspective of naval combat and the "tools" that a combat modeler must be familiar with in order to understand the nature of naval warfare. This chapter discusses some aspects of naval combat from *Fleet Tactics*, shows the change in the applicable formulas for naval battles, and introduces tactical decision aids.

B. CORNERSTONES OF MARITIME WARFARE

In understanding the history of naval warfare, five cornerstones of naval combat must be kept in view at all times. (Hughes, 1986, pp. 24-25):

- Men matter most,
- Doctrine is the glue of tactics,
- To know tactics, know technology,
- The seat of purpose is on the land,
- Attack effectively first.

The cornerstones of naval combat will be discussed in class.

C. PROCESSES OF NAVAL COMBAT

Naval combat is best described as a collection of processes, called activities in Chapter II. For combat on the seas, the processes can be reduced to delivery of firepower, counterforce activity, scouting and anti-scouting. The concerted effects of these processes are directed by the commander by a C^2 process and opposed by the enemy's C^2 countermeasures. The result is delivered combat power.

The processes fundamental to naval combat are (Hughes, 1986, pp. 145-146):

- Attrition. Naval combat is an attrition process which results from the effective delivery of firepower.
- Scouting. The ability to strike effectively first is a direct result of the scouting process.
- C^2. The conversion of potential into combat power is the process of command and control.

The processes of shooting, scouting and C^2 have antitheses. These are employed by a commander in the protection of his forces. The activities are designed to reduce the enemy's ability to deliver effective firepower, his scouting effectiveness and C^2 ability. These functions are called counterforce, anti-scouting and C^2 countermeasures (C^2CM). The purpose of counterforce is to reduce the effect of enemy firepower by defensive fire, protective armor, damage

control and other such means. Anti-scouting uses whatever means available to disrupt enemy scouts and delay detection or tracking, in order to allow the advantage of the first strike to friendly forces. C^2CM activities are those associated with disrupting the enemy's ability to make decisions, disseminate battlefield information and deliver orders to his own forces.

Space and Electronic Warfare (SEW), introduced in Chapter II, is a Navy term and organization that governs the development of systems associated with scouting and anti-scouting, and for pragmatic reasons, also many systems for C^2 and C^2CM. It has had widespread effect toward giving these systems the attention they deserve for modern naval operations. As a result, the Space and Electronic Warfare Commander (SEWC) has gained full warfare commander status in the Navy's Composite Warfare Commander (CWC) structure.

Command and Control Warfare (C^2W) also previously defined in Chapter II is an all-service concept which attempts to protect friendly C^2 processes and diminish the enemy's C^2.

D. GREAT TRENDS AND CONSTANTS OF NAVAL COMBAT

In order for a modeler to develop good models for predictions, he must understand the trends of the processes being modeled. Then the trends may be reflected in the model which attempts to emulate the processes. A model of naval warfare must be true to the nature of combat at sea. Several of the key trends which have affected the process of naval combat are (Hughes, 1986, pg. 196):

- The shift of emphasis from speed of platform to speed of weapon.
- Scouting has replaced the importance of ship maneuverability.
- The range of weapons has increased significantly.
- The lethality of weapons has increased significantly.
- Counterforce (cover, deception, dispersion, defensive firepower) has replaced the notion of survival through armor, sheer size, better damage control, etc.
- Not only has the scouting process gained in importance, but the rate and range of scouting and surveillance has increased significantly.
- To circumvent the increase in effectiveness and range of weapons, anti-scouting has played a large role to keep forces undetected for as long as possible.
- The application of pulsed power may result in a victory for an inferior force in modern naval battles that was not possible until World War II.

The constants which must be accounted for in a model must be understood and enforced in a manner similar to the trends. Several of the key constants of naval warfare are (Hughes, 1986, pg. 197):

- The purpose of maneuver is to create an advantage in position relative to the enemy.
- The ability to fire effectively first is the primary way to win a naval battle.
- Defense plays a smaller role in naval combat than in land combat.
- There is never enough scouting capacity or information.
- Commanders must be prepared to reallocate resources to improve scouting or surveillance even at the expense of firepower.

E. EVOLUTION OF NAVAL TACTICS

The history of naval combat has developed through several notable periods of evolution in both tactics employed and technology available. The periods of interest include: the age of the fighting sail and the smooth bore gun, the age of steam and rifled gun, the age of the aircraft carriers and the missile age. By means of class lectures, the student will gain an understanding of the utility of attrition-based models to describe the six processes of naval combat.

1. Age Of The Fighting Sail And Smooth Bore Gun (Hughes, 1986, pp. 40-54)

In the age of the fighting sail and smooth bore gun we see: the noticeable effect of concentration of firepower in the individual ship and the first use of C^2, the purpose of which was "merely" to control and maneuver fleets effectively. Concentration of firepower was achieved in this period by two basic means. The first was to put more guns on a ship by producing double and triple deck ships to fight in the line. Only one ship's gunfire could be concentrated against another, so that the conditions for the square law held for single ship duels. The second means was the fighting column of ships which allowed a commander to bring all of his ships together to form a concerted effort in battle. But because effective range of the guns was short, duels between individual ships resulted, and the linear law's condition held (Figure 13) for the column as a whole. The command of ships was simplified by the fighting line by placing the flagship in the middle of the line so that message flags could be read by all the ships in the line.

Example of one side's gun range while in a column in order to concentrate firepower

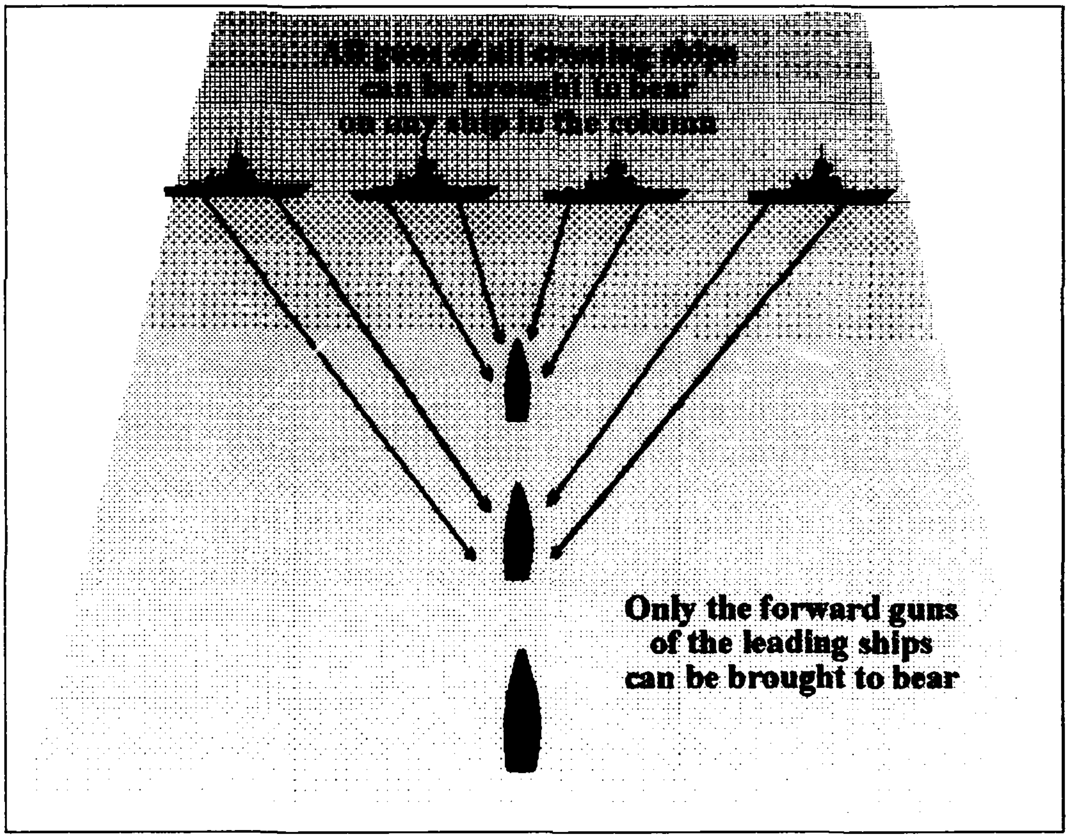
Figure 13

2. Age Of Steam And Rifled Gun (Hughes, 1986, pp. 55-84)

The age of steam propulsion and the rifled gun was marked by technological advances in fabrication of steel hulls and weapons. One of the biggest trends highlighting this period was the use of steel and armor in warships. The stronger, armor protected ships could take more direct hits and still be a strong adversary. In addition to being stronger, the increase in maneuverability provided by steam propulsion plants allowed the commander to go directly into the wind, with new possibilities in formation and strategies. Tacticians were at first in disagreement over how best to use these ships in naval combats, some favoring their use as rams to swiftly destroy an unsuspecting line of ships.

Another important trend was a marked increase in the range and lethality of weapons brought on by rifled guns. The range of effective weapons was drastically increased from 300-500 yards to 8-10 miles. The increased range of weapons gave fleet commanders a new possibility for concentrating force.

These new weapons allowed the commander to concentrate the firepower of any and all of his ships against any ship in a concentrated enemy formation, and so square law conditions held between whole fleets. This long range fire settled the tactical debate and led to the reemergence of the battle line or fighting column (Hughes, 1986, pg. 67). Crossing the enemy's "T" then became the tactical goal of every fleet (Figure 14). The importance of being able to quickly form a single battleline out of several columns (employed for cruising) emphasized the need for more scouting and reconnaissance information.



Crossing the Enemy's "T"

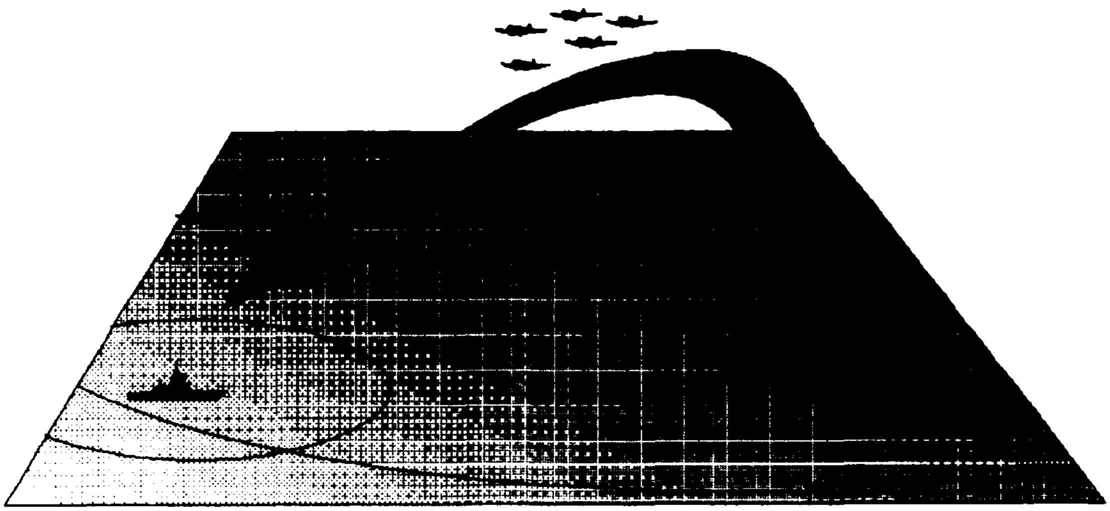
Figure 14

Another debate was whether the tactical commander should be in the middle (for signaling purposes) or in the first ship (for simplified follow-the-leader maneuvering). The wireless radio and extensive signal codes developed during this period altered the command and control aspects of naval combat. The flagship no longer had to be placed in the center of the formation and the scouting and reconnaissance ships could be placed well out of sight of the main formation yet still communicate by radio.

3. Age Of Aircraft Carriers (Hughes, 1986, pp. 111-139)

The age of steam and the rifled gun gave way after World War I to the age of aircraft carriers. The effect that naval air power has had on naval combat in terms of trends, tactics and strategy is rivaled only by the effects the missile has had on modern naval combat scenarios. The ability to launch aircraft from the carriers and attack at ranges twenty times greater than guns had decisive effects on the sea battles of World War II.

Aircraft squadrons gave naval forces two major improvements over the age of steam. The first improvement involved the range of scouting and reconnaissance efforts. Aircraft provided long range scouting, which dramatically affected the chances of making the first strike. The second improvement involved the concentration of firepower of an air wing in time. The result was a "pulsed firepower" battle (Figure 15). A one-page paper found in the readings, "Naval Pulsed Firepower Combat Model," provides a model that shows the outcome of these pulsed fire engagements between aircraft carriers and their air wings.



The increase in range and lethality due to carrier pulsed firepower

Figure 15

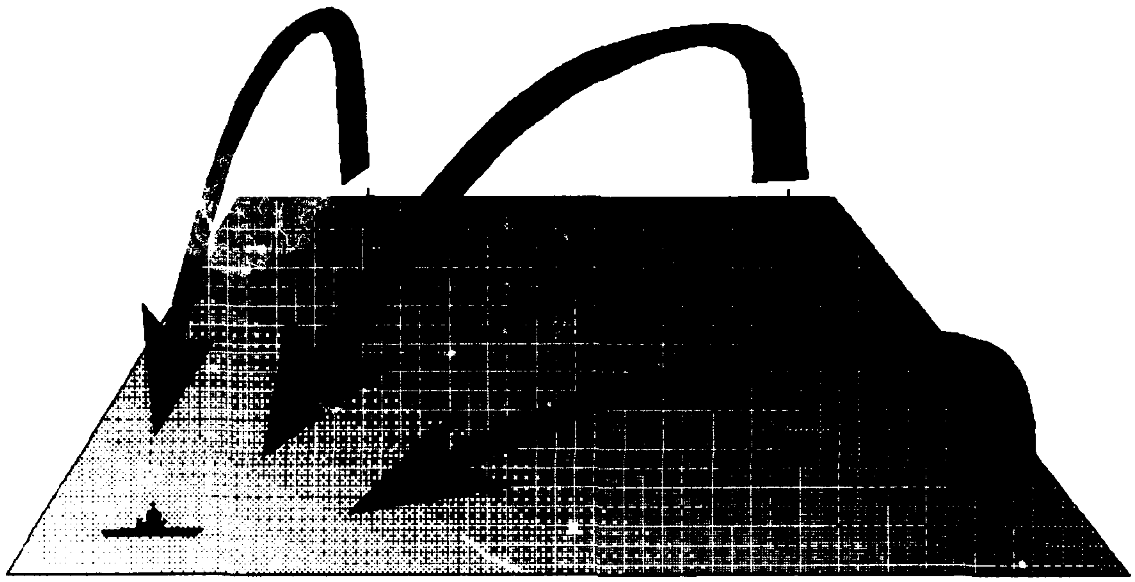
The age of the aircraft carrier provides an excellent opportunity to apply attrition modeling to five actual engagements observed during World War II. In *Fleet Tactics*, Hughes applied a simple tactical model of carrier warfare to demonstrate how a pulsed firepower attrition model accurately describes the carrier engagements in the Pacific (Hughes, 1986, pp. 93-103). This model fitted the historic battle outcomes and showed that the Lanchester continuous fire model was obsolete.

One of the most important of the trends observed in this period was the technological breakthroughs in sensory equipment. With the capability to conduct large air strikes hundreds of miles away from the carrier, the need for longer range sensor information is obvious. The technological revolution in radar, electronic support measures (ESM), jamming and air defense communications all

coordinated in a combat information center (CIC) were paramount to the success of US forces had in naval battles with the Japanese.

4. Age Of Missiles (Hughes, 1986, pp. 240-264)

The increases in range and lethality of weapons which occurred during the age of the aircraft carriers were overtaken by yet another transition by the introduction of land air and sea based missiles. The trend of developing longer reaching weapons and the development of long range tactical and strategic missiles has had significant impact on the tactics of naval combat. Inclusive with the range and lethality of these new missiles are: a potential to concentrate firepower from widely separated ships and aircraft (Figure 16), a need for better scouting and reconnaissance equipment and strategies -- including the roles of decreasing the enemy's ability to scout effectively and the need for a more coordinated C^2 system to deal with an environment to enhance friendly force's capabilities while stifling the enemy's ability to perform well -- C^2CM. (The model described in *Fleet Tactics*, Chapter 10, will be presented in a class lecture. It takes into account the current capabilities of long range missiles and the ability of forces to scout and perform C^2CM functions to enhance the probabilities of a first strike.)



The effect of concentrated missile firepower

Figure 16

F. FUNCTION OF SCOUTING

The function of scouting has been a recurring issue in naval combat from the earliest age of the sail ship to the modern age of missile warfare. The need to know not only where the enemy is but what his capabilities are, has been shown to turn many battles into victories for the inferior fleet. The importance of scouting in naval tactics provides a dilemma for the current force commander. On the one hand, scouting provides obvious benefits in the advantage given to the force which conducts the most effective scouting. On the other hand, scouting reduces the number of forces which can be drawn upon for firepower while the scouts are engaged in scouting and reconnaissance. The tradeoff between ready firepower and forces engaged in search ard tracking must be carefully weighed by the force commander (and combat modeler) in order to determine an optimum balance.

G. TACTICAL DECISION AIDS (Snyder, 1988, pp. 49-53)

Such problems as scouting versus firepower and choices of weapons to use against specific targets in a modern conflict has led to the use of tactical decision aids. The most significant origin of decision aiding began in World War II as operational analysis work was being conducted to help commanders make better tactical decisions and use the best force employment techniques (Snyder, 1988, pg. 49). The development of these decision aids is directly related to being able to follow the trends and constants of naval combat and the ability to apply the proper modeling parameters to the situation.

H. RELEVANCE TO FURTHER COURSES

This chapter examined the trends and constants of naval warfare drawing much of its material from *Fleet Tactics*. The chapter shows how naval warfare has evolved, and thus how modeling formulas have likewise evolved. In order to determine how combat can be effectively modeled, the student must have some sense of how it has changed over the years, what factors have caused the change and how those factors can be applied to other areas of warfare in order to try and predict the changes there. This sense of historical evaluation gives the student an effective tool which, when applied to other areas of study, can help bring into focus "the big picture." Modeling and combat analysis do not take place within a vacuum and there must be a sense of "how we got where we're at" in order to understand constant, unchanging factors and possible future trends and how they can affect what may be required down the road. As we've said before, the old saying goes, "It's not, 'let's model so we can understand combat,' but 'let's understand combat so we can model it.'"

Several courses in the curriculum use ideas presented here along with material from Chapter VII, which is more centered on ground combat. OS 3008, Analytical Planning Methodology; OS 3603, Simulation and Wargaming; CC 4001, C^3 Systems Engineering; CC 4003, C^3 Systems Evaluation; CC 4750, Military C^3 Systems; and CC 4913, Policies & Problems in C^3, all deal with naval warfare in one way or another. Either they explore the modeling techniques of attrition based models, such as OS 3008 and OS 3603, or they deal with larger issues and problems within the Navy itself, such as CC 4750 and CC 4913. In either case, the information presented within this chapter gives valuable background as to the history of naval warfare, trends contributing to that history and how the Navy "fights the ship."

I. REVIEW QUESTIONS

1. List the five cornerstones of maritime warfare as defined by Hughes and describe how each affects command and control.

2. Describe the processes that result in delivery of combat power at sea. Contrast these with the functional approach of SEW and C^2W.

3. Describe the evolution of combat power at sea, in terms of changes in weapon range and lethality and the effect on choice of model of naval combat at different periods of history.

4. Assess the impact of changes in weapon delivery mode on the importance of the warship maneuverability. Will new weapons have a similar affect on the desirability of aircraft maneuverability?

5. Why is it so important in naval warfare to attack effectively first? How can this capability be maintained in peacetime by a country whose foreign policy denounces a first strike capability?

6. How have advances in communications technologies affected naval command and control?

7. Given the following:

$A_o =$	12	$B_o =$	8
$a_1 =$	0.5	$b_1 =$	0.5
$a_2 =$	2	$b_2 =$	2
$\alpha =$	2	$\beta =$	4
$\sigma_A =$	0.5	$\sigma_B =$	0.5

a. Use the Naval Pulsed Firepower Combat Model to compute the number of survivors, A_1 and B_1, for a single exchange of salvoes. Answer: $a_1 = 7$, $b_1 = 4$.

b. Side A determines that if he can cut his defensive firepower in half ($a_1 = 0.25$) he will double his offensive targeting accuracy ($\sigma_A = 1.0$). What effect will this have on A_1 and B_1 (assuming all other values remain constant)? Answer: $a_1 = 5.5$, $b_1 = 0$.

8. How has the development of stand-off missiles impacted the development of naval tactics? How does this affect the modeler and the modeling process?

VII. NON-ATTRITION BASED MODELS

AIM:

We have seen that attrition models of ground combat do not cover important factors such as suppression, friction, strong positions, maneuver and fighting spirit. Now we show that these attrition models are not adequate in explaining the outcomes of battles, and how an advantageous position or maneuver play important roles in determining the outcome of a battle, in addition to the commander's interpretation of the situation. "Breakpoints" and their use in current modeling practices are examined along with some non-attrition modeling techniques in use.

OBJECTIVES:

- Present the idea of mission accomplishment being measured in terms other than attrition, explicitly domination of the enemy (or control of the situation to one's own ends)
- Examine the role of suppression as a measure of dominance.
- Discuss McQuie's article on breakpoints
    - Introduce breakpoint phenomenon
    - How breakpoints are established
    - Examine the trends of dominance of maneuver over attrition
    - Introduce the effect of battlefield impressions on command decision vice measuring actual losses during combat
- Emphasize that a typical engagement results in a withdrawal of forces vice a fight to the death

- Discuss methods of estimating combat potential and power
    - Use of fire power indices as combat potential
        - The basic form of the relationships and the applications
        - The limitations of fire power indices
    - The QJM approach to represent combat power
        - The basic approach of the relationship and the applications
        - The limitations of QJM
            - The dimensional incompatibility of the model
            - No power distribution and tactics ("black box effect")
- Present a model of nuclear arms race as an example of graphical modeling techniques
- Discuss the Russian Correlation of Forces and Means (COFM) method as an extreme use of decision aids using non-attrition models
    - The basic form of the model
    - The limitation of the model

READINGS:

1. McQuie, Robert, "Battle Outcomes: Casualty Rates as a Measure of Defeat," *Army*, pp. 30-34, November 1987.

2. Dupuy, Trevor, *Understanding War: History and Theory of Combat*, pp. 39-50, 81-89, 1987.

3. Giordano, Frank and Maurice Weir, *A First Course in Mathematical Modeling*, pp. 4-15, 1985.

A. MISSION ACCOMPLISHMENT

At this point, the reader should recognize the limits of attrition models. Typically, the final outcome was determined by a battle to the end where one side loses most or all of its forces. In reality, this situation rarely occurs. Analysis should be developed that more closely resembles ground combat with non-attrition models.

One approach is to look at how a commander would answer two questions: "How many losses am I willing to suffer before conceding my aim (mission) to the enemy?" and "What other factors influence my decision to retreat or surrender?" What casualty total is sufficient to cause the commander to admit defeat? Is the number as high as 50%, or is it closer to 10%? In what ways is it dependent upon the commander, his mission and the particular engagement?

What factors affect the commander's decision to admit defeat and how can these factors be modeled for analysis? The possibilities include: domination -- if a commander feels that he is outmatched in the battle, he may retreat early; maneuver -- if one side's forces are outflanked, they will be surrounded or if they withdraw before they are incapable of maneuvering and become forced to surrender; and the environment itself -- a commander whose forces are battling in an unfamiliar environment may not feel as comfortable with the high casualty rate and may retreat earlier than expected. The student should pause here and reflect on other possible factors.

The purpose of this chapter is to examine the limited number of models and techniques for accounting for some of the other factors which strongly influence combat outcomes in the real world.

B. SUPPRESSION

In his book, *Understanding War: History and Theory of Combat,* Trevor Dupuy (Col. USA, Ret.) addresses the importance of suppression in determining the outcome of battles. He defines suppression as "the degradation of hostile operational capabilities through the employment of military action that has psychological and/or physical effects [which] temporarily [impair] the combat performance of enemy forces and personnel who have not themselves been killed or wounded" (Dupuy, 1987, pg. 252). As discussed earlier, the use of suppression limits a force's ability to achieve the hyperbolic attrition effects predicated by Lanchester's Square Law.

The effects of suppression were readily addressed by S.L.A. Marshall when he observed that under the influence of enemy fire, soldiers would neglect the training and doctrine taught to them, calling for return of fire, to force the enemy to also go to ground {refer to Chapter V reading: (Schneider, 1985, pg. 104)}. Schneider's account of the Battle of Gettysburg graphically depicts the effects of terror, induced by suppression, on battlefield discipline {(Schneider, 1985, pg. 97) not included in your reading}. According to Schneider, many of the weapons recovered after the battle were loaded with multiple rounds, to the point of becoming a veritable pipe bomb, in addition to improperly loaded weapons which became essentially useless. The effect of suppression and demoralization effectively removed many soldiers from the battle. A more recent example of the effects of suppression on training and doctrine could be seen during Desert Storm. Iraqi Scud missile launchers, the object of intensive search and destroy missions by Coalition air forces, had little time to fully set up and aim their missiles. As a result, there was little or no accuracy in missile delivery, compared with what was

technically possible. Thus, by maintaining constant pressure on the Scud missile crews, Coalition air forces effectively suppressed the effectiveness of weapons delivery.

Dupuy says that the amount of suppression is a function of the explosive power of the munitions employed, the number of rounds fired and the rate at which the fire was delivered. Additionally, the period of time that the suppressive fire was delivered impacted upon its effectiveness: the longer the fire was delivered, the greater the cumulative effect.

Dupuy notes that the effects of suppressive fire are blatantly left out of both wargaming and field exercises. He contends that it is essential for US personnel to be exposed to the reality of suppression and its impact on the battlefield.

Thus, more data on the effects of suppression should be gathered. Such data would provide a means of measuring the ability of a commander to dominate the enemy through firepower. Marshall's analysis revealed that forces held down by suppressive fire for just a couple of days became morally broken, and attempts to continue the engagement using those forces were futile (Schneider, 1985, pg. 104). This situation became readily evident during Desert Storm when, after being battered by weeks of heavy bombings, the Iraqi ground forces quickly surrendered to Coalition forces after little or no resistance. Thus, through suppression and demoralization, a force could dominate the battlefield and win its objective with relatively small attrition on his side, and sometimes the enemy's side as well.

C. BREAKPOINTS

Robert McQuie's article, "Battle Outcomes: Casualty Rates As a Measure of Defeat" (*Army*, Nov. 1987) examined the relationship between casualty rates in

modern warfare and conflicts, and battle outcomes. McQuie referred to the moment when a force commander accepts that the battle is lost as "the breakpoint" (McQuie, 1987, pg. 33). In his analysis of data from 80 modern battles accumulated by the Historical Evaluation and Research Organization (HERO), McQuie attempted to find a cause-and-effect relationship for battle outcomes.

McQuie found that on average, defenders were willing to accept a casualty ratio, with respect to initial force strength, that was twice as great as an attacker's before admitting defeat. Nonetheless, he found that the median casualty levels for defenders and attackers were only eight and four percent, respectively. This was far less than the levels normally used for combat simulations to determine breakpoints. Exchange rates experienced prior to breakpoints followed the same general pattern: defenders were willing to accept losses at a rate approximately two and a half times as great as attackers.

But McQuie also concluded that neither the number of casualties experienced in battle nor the rate at which they were experienced was a driving factor in the outcome of the battle. More significant to the outcome of battles were the ability of the enemy to maneuver, the withdrawal of adjacent friendly forces and a commander's perception of near-term developments. These three factors may have a high degree of correlation, in that, as a commander recognizes the ability of the enemy to envelop his forces or his inability to effectively position his own forces, he may sense the futility of continuing the exchange. This is compatible with Marshall's finding that once the thrust of an attack is broken and the attackers are forced to go to the ground, it is very unlikely that the impetus can be restored (Schneider, 1985, pp. 104-105). Thus, McQuie holds that effective commanders seldom commit their forces to a suicidal situation.

As pointed out by Morse and Kimball, the data available to the commander is often tainted (dirty). It may reflect inaccuracies induced by the heat of battle and overestimation of both casualties sustained by friendly forces and casualties inflicted upon the enemy. Because of the inaccuracies, the *perception* in the mind of the decision maker is the basis of the decision. This may cause him to withdraw from a battle he can win or continue even when the battle is beyond redemption. McQuie holds that, in battle, commanders are "prudent and cautious" with respect to continuing an engagement which appears to be unwinable.

McQuie concludes that most battles are decided by factors other than casualties. Further, he found that the majority of engagements were terminated with less than a ten percent casualty level. Clearly, except in extreme cases, a fight to the death is atypical for land combat, and thus the value of Lanchester attrition models is limited.

D. METHODS OF ESTIMATING COMBAT POTENTIAL AND POWER

1. Firepower Index

A simple non-attrition modeling technique employs the use of firepower indices. A firepower index aggregates a set of heterogeneous elements of force into a single number which represents the combat potential of the forces. To do this, the model assigns a unit value to the weapon with the lowest kill potential (such as a rifle) and scales the values for the other weapons relative to the lowest valued weapon. The individual weapon index is then multiplied by the number of weapons of that type in the force. The sum of the values are compared for each side and the highest scoring side is <u>assumed</u> to have the greater combat potential. It is accepted that the comparison cannot determine relative combat <u>power</u>,

because that depends on the two commanders' actual deployments in battle. The firepower indices assigned are generally determined on an historical basis, by examining the effects of the various weapons relative to other weapons over numerous battles.

Table 1 is an example of a firepower index model:

TABLE 1

Force Type	Unit Value	Number of Units	Index
Infantry	01	200	200
Tanks	20	20	400
APCs	10	10	100
Artillery	15	20	300
Total			**1000**

Although this is a better model than just counting the number of forces on each side, this model suffers from several serious drawbacks. First, the firepower indices are static values which do not take into account such factors as effectiveness in different terrain or environments, mobility or offensive versus defensive uses. Second, the indices are assumed to be linear -- the sum value of 1 tank + 1 tank = 2 tanks. This discounts the additive firepower effect of multiple units and the psychological value of advancing with large divisions vice a few tanks. This linearity also assumes that 100 men are 100 times as effective as a single man thereby neglecting the problems of friction associated with controlling and advancing the much larger group.

Finally, the model suffers from synergism in that the sum of artillery, tanks, infantry, etc., is more than just the values assigned to the organic units. This is a static model which is only effective in comparing the potential of two sides. It cannot be used to estimate battle outcomes or probable losses, but only which side has the advantage in forces.

2. Quantitative Judgment Method (QJM)

In the early 1800's, the influential works of Carl Von Clausewitz implied a Law of Numbers that would model military conflict. This work (On War) was seen by Dupuy to correspond to his Quantitative Judgment Method (QJM). The QJM was developed in the 1950's to account for a number of factors which influence the outcome of battle but were not accounted for in the attrition models presented earlier.

In *Understanding War: History and Theory of Combat*, Dupuy derived a combat power formula based on Clausewitz's Law of Numbers. The Law related combat power (P) to the number of troops available (N), a term representing the variable factors affecting the force (V), and a value assigned to the fighting quality of the troops (Q) by the simple relationship:

$$P = N \times V \times Q.$$

Dupuy's QJM combat power formula derivation may be obtained through a three step process (Dupuy, 1987, pp. 81-89):

- Replace the number of troops (N) with force strength (S).
- Quantify and define the variable factors (V_f) which influence the circumstances of combat on the force.
- Replace the troop quality factor (Q) with a relative Combat Effectiveness Value (CEV).

The QJM method replaced the force manpower term with a force strength term, a "Firepower Index," in order to account for the lethality and effectiveness of all weapons in the force. The force strength term developed in the QJM is based on historical data and empirical results, adjusting over the course of history in order to obtain current values. Force strength corresponds to combat potential. The QJM model has determined a finite number of variables which affect combat, classified as either environmental (terrain, weather, etc.) or operational (posture, mobility, etc.). Dupuy conducted a historical analysis, assigning to each factor, a value based upon its importance in combat and its relative impact upon effectiveness. Finally, the Combat Effectiveness Value is the ratio of theoretical combat outcomes to actual outcomes and is a substitute for the Clausewitzian term (Q), in that, it is a measure of relative combat effectiveness of one side's force against the other due to leadership, training, etc. Thus, the resulting QJM combat power formula is:

$$P = S \times V_f \times CEV.$$

The limitations of the QJM lie in the historical approach taken to obtain the values of force strength (S) and Combat Effectiveness (CEV). This model is a statistical curve fitting endeavor with a large number of parameters, it is challenging to obtain a good input for CEV. Another significant drawback is that this model does not describe how the different factors actually affect the battle and does not account for the dynamics of combat such as the opposing tactics or the effects of maneuver and suppression. This model does address the problem of how to distribute force across a battlefield in order to obtain the optimum use of combat power.

E. GRAPHICAL MODELING TECHNIQUES

Students were first exposed to the use of graphs when learning to analyze simple linear equations. Later, this technique was applied to complicated systems of linear equations. In their book, *A First Course in Mathematical Modeling*, Frank Giordano and Maurice Weir use this technique for modeling one complex relationship. The technique was applied extensively by the Arms Control and Disarmament Agency (ACDA) and other arms reduction treaty organizations.

Graphical analysis of complex issues requires that the issues be reduced to the relationship between a single independent variable and a dependent variable. In their analysis of the nuclear arms race between the US and the former Soviet Union, Giordano and Weir limited the variables to the number of missiles or warheads possessed by either country. In order to model the close interrelation between the two force structures, the graphs of each country's projected missile requirements, which satisfied their own strategies, were overlaid. The result was a method of determining the effect of changes of one country's strategy to the number of weapons required by the other.

In general, the limitation of this method is a common one -- the results require subjective interpretation. This may be seen with the nuclear arms model. The actual number of missiles required to satisfy the friendly strategy of each country in the model is not explicitly determined. Nor is the survivability index which determines the actual slope of the curves used to depict the number of missiles or warheads possessed. Thus, the model is more beneficial in describing the effects (trends) caused by changes to either country's nuclear strategy than it is in prescribing force levels and policies.

Many policy analysts and negotiators regard the model's "weakness," its strength: it provides a vivid assessment of the likely effects of strategy or policy changes. Similar models can be generated for other complex military problems. The key is to agree on critical relationships governing the problem and then describe them graphically.

F. RUSSIAN CORRELATION OF FORCES AND MEANS (COFM)

In order to prepare for war, the former Soviet, and now, Russian military always considered it important to study history scientifically (logically and quantitatively). The result of years of operations research in military history is the Russian Correlation of Forces and Means (COFM) still in use in Russian military doctrine. An article in the *Soviet Military Encyclopedia* (1979) emphasized that COFM is an operational, tactical and strategic model used at all echelons of the military (Dupuy, 1987, pp. 39-50). The aim of COFM is to give the fighting power (we would say combat power) of both sides, based on a correlation of the forces available to each side and the means required to achieve stated objectives, in order to compute the probable victor and estimate the range of casualties likely. Thus, the Soviet view took a more sanguine view over the predictive power of combat models than the US armed services.

According to doctrine, a COFM-computed margin of advantage (a ratio) is to be gained at the critical fronts prior to an attack. As a battle progresses, the model is updated and if an insufficient margin is determined to exist at critical places, then forces are shifted appropriately to enhance the margin to ensure victory.

Like Dupuy's QJM, the COFM model also takes into account variables such as: training, experience of command, motivation, reconnaissance capabilities, etc.,

which are related on both sides with numerical values, or simply as "superior" or "inferior." As with the QJM, these values are difficult to obtain a priori.

A limitation of the COFM lies in rather rigid adherence to the computation. For instance, if the margin drops below a predetermined value, doctrine says that action must be taken to enhance the margin or else the mission will be at too severe a risk. In Western eyes, such a heavy a reliance on the statistical nature of combat is excessive.

G. RELEVANCE TO FURTHER CURRICULUM COURSES

In Chapter V, Lanchester attrition-based laws were introduced in order to give the student the skills to numerically evaluate individual or group combat actions. The formulas were based on the premise that once one side's forces had ceased to exist, the conflict was over. We then looked at factors in actual combat that are not given due attention in attrition models. As was shown, rarely is the case that one side will fight "to the last man." The commander will weigh many factors both known and unknown: how much loss he can afford to carry, at what breakpoint is the loss too great, morale on both sides, what future choices are available, etc. This chapter also introduces various alternatives to attrition warfare thereby giving the student a more rounded picture both of combat and combat modeling. Insofar as ground combat is concerned, this chapter along with Chapter V should be viewed as two parts of a whole, for the concepts of each are dependent upon the other, attrition based models of ground combat need an insertion of non-attrition based concepts in order to behave more like reality. Non-attrition based concepts need the structure and rigor of attrition based modeling in order to escape the threat of becoming mere speculation and pure

conjecture. Taken as the second part of the whole, the concepts introduced in this chapter balance the concepts from Chapter V for further courses in the C3 curriculum.

In OS 3008, Analytical Planning Methodology, and OS 3603, Simulation and Wargaming, non-attrition concepts are examined hand-in-hand with the Lanchester laws in order to introduce other forms of combat analysis, namely wargaming, simulation and field tests and experiments. While the bulk of the material is used in OS 3008, especially firepower indices, QJM, graphical modeling techniques and Russian COFM theories, OS 3603 gives the student additional opportunity to examine the concepts of breakpoints, suppression and mission accomplishment by using military wargame analysis and planning in actual wargaming scenarios. CC 4003, C^3 Systems Evaluation, and CC 4913, Policies and Problems in C^3, use the chapter's concepts in examining actual systems and real world C^3 issues.

H. REVIEW QUESTIONS

1. List in order of importance three factors which affect a commander's decision to retreat in battle.

2. Why is it difficult for the effects of suppression to be quantified using current modeling techniques? Why is suppression of concern to commanders on the battlefield if the results are not readily measurable?

3. Historically, what median percentage of losses have commanders likely accepted before retreating or breaking an attack? How can this percentage of losses be useful in the attrition models studied thus far?

4. How can the use of firepower indices be used to evaluate what we defined in the theory of combat as combat potential? Which of the two potentials does it most likely measure?

5. What are the limitations of the firepower index modeling technique? Are these serious limitations?

6. How does the Quantitative Judgment Model (QJM) alleviate some of the problems with the firepower index model?

7. If graphical models described in Weir provide no quantitative results, then what value is there in applying his techniques? Contrast descriptive (explanatory) modeling with prescriptive (exhortatory) modeling. Evaluate the usefulness of graphical techniques using the good model characteristics given in Chapter III of the text.

8. With your understanding of the usefulness and practicality of combat modeling, analyze the strengths and weakness of the Russian COFM technique with respect to: decision making, reliability, accuracy, flexibility, communicability, etc.

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VIII. CURRENT MODELS/SIMULATIONS/WARGAMES

AIM:

Introduce the student to modern models, simulation and wargames that are currently in use by the various services. Provide basic information about the models and explain how the models have been used to make C^2 decisions (as decision aids).

OBJECTIVES:

- Have an understanding of the structure, contents, purpose and use of the following military combat models, simulations and wargames:
  - Janus
  - RESA
  - CFAW
- Understand the principles of Chaos Theory
- Introduction to examples of Decision Support Systems and Tactical Decision Aids

READINGS:

1. Hughes, Wayne, Jr. and J. Larson, *The Falklands Wargame*, Appendix G, 1986.

2. Antigiani, Robert and Michael Gaffney, "Chaos and Command: Contemporary Science and Leadership in the Nelson Style," pp. 1-27, 1990.

3. Gaver, Donald, "Naval Tactical Decisions Under Uncertainty: Some Case Studies," *Naval Research Reviews*, pp. 41-43, 1987.

4. Bolmarcich, J., "On the Distribution of Combat Heroes," *MORIMOC II Workshop Proceedings*, pp. 667-700, 1989.

5. Dunnigan, James, "Inserting the Human Factors into Combat Models," *MORIMOC II Workshop Proceedings*, pp. 723-733, 1989.

6. Dunnigan, James, "The Failure Rate of Division Commanders After 90 Days of War," pp. 1-17, 1990.

7. Schecter, Richards and Romberg, "Tactical Deterrent Effects Model," *MORIMOC II Workshop Proceedings*, pp. 419-460, 1989.

In this primer, the student has seen several aspects of elementary modeling (freshman level) and some relatively advanced (graduate level) aspects of the purpose and use of models, measures of their effectiveness and performance to be expected from them. Many examples of mathematical modeling techniques (such as attrition, non-attrition and navy battle modeling) were introduced in order to understand the principles and theories behind them. To this point, we have not examined any working models and wargames in use today. While any list of "current" simulations would be out of date within a year, we can present several current "standing" models/wargames/simulations and some up-to-date theories and decision aids in order to provide an introduction to the mechanics of "how the games are played."

A. JANUS

Janus is a high resolution *stochastic interactive combat* model used to support the analysis of hardware system development efforts, employment methodology, tactics and to assist in the training of troops. Named after the dual-faced Roman god of beginnings and endings, it was originally developed at Lawrence Livermore National Laboratories and then adopted for use by the US Army Training and Doctrine Analysis Command The model functions as a Cost and Operational Effectiveness Analysis tool, one of the categories of model uses listed in *Military Modeling* (Hughes, 1989, pp. 227).

The Janus model employs discrete-event simulation to represent the exchange of fire between two opposing forces. Probability techniques are used to determine the combat outcomes. Individual combat elements are modeled, not aggregated units. This allows for the detailed assessment of single weapons' performance in

combat, as well as the interaction of several weapons systems employed within a given theater.

The model is highly hardware and software intensive. The system documentation identifies a requirement for at least a Micro-VAX II minicomputer with a variety of peripherals and 85,000 lines of Fortran code, in addition to various utility and database handling routines. Currently there is a version of Janus(T) at TRAC Monterey on the Naval Postgraduate School grounds.

B. INTERIM BATTLE GROUP TACTICAL TRAINER

The Interim Battle Group Tactical Trainer (IBGTT), also known as the RESA (Research Evaluation System Analysis) model at the Naval Postgraduate School, provides an opportunity to train participants on the importance of command and control in naval operations. The model uses discrete-event, real time, man-interactive, computer-aided *simulation to wargame* two opposing naval forces, Blue and Orange. Emphasis is on Battle Group operations. The model uses NTDS (Naval Tactical Data System) symbology in order to represent naval forces, with color enhancement for friendly, neutral and hostile forces. A controller position oversees the game and may play the role of the Orange Force commander.

Each force has several consoles, both geographic and alphanumeric, which allow interaction with the system database and controller. Each position is provided intelligence information from the system database. This information comes from own force sensors, organic and external. Additional information may be gained through search with organic surveillance systems and communications with other players. Thus, failure to search wisely or pass new information

between players will result in an incomplete picture of the battle situation and complicate attempts to properly control forces.

RESA, or IBGTT, models the operations of opposing naval battle units, simulating the actions of aircraft and ships based upon inputs from players. Command of some individual units, such as aircraft or launch facilities, are subject to the real-time constraints of logistics requirements (e.g., refueling, rearming, etc.). These and other factors help to complicate the decision making process. On the whole RESA, or IBGTT, is widely accepted as an effective tool, offering trainees an opportunity to make command decisions in an atmosphere of stress and limited information. A version of RESA resides in the Warlab at the Naval Postgraduate School.

C. CONTINGENCY FORCE ANALYSIS WARGAME (CFAW)

The Contingency Force Analysis Wargame (CFAW) described in the US Army Concept Analysis Agency document, "The Falklands Wargame," is a force-on-force, attrition based model which can be used by the Army Concepts Analysis Agency to evaluate the reasonableness of operation and contingency plans for joint forces at the theater level. The model supports testing of hypothesized plans for littoral warfare scenarios, over different terrain areas as specified by the players. It is described here because it was extensively used for testing war plans during the early days of Desert Shield and to a lesser extent, the Desert Storm assault.

CFAW models the interaction of a variety of combat and combat support functions ranging from intelligence and logistics to ground and air combat. The combat potential of each opposing element is generated from a database built by the players prior to the start of the game. Characteristics of each weapon system,

to include probability of detection target acquisition and kill, are provided during game preparation. The model uses this information to generate aggregated combat results on company, battalion or brigade size units at discrete intervals. Resulting force strengths are compared to pre-set percentage levels in order to determine the new posture of the two opponents. Should a unit's strength fall below a predetermined value (e.g., 75%) relative to its initial level, it is automatically removed from further play.

Players make all command and control decisions. The model requires that the players must recognize critical decision points and take appropriate action to redirect their forces. Since the model has the capability to be replayed from any point, the effects of different decisions can be played and the outcomes compared. However, the model is highly probabilistic, thus a particular decision will not have identical results each time the model is played under identical decisions and actions.

D. CHAOS THEORY

Chaos theory is one of the latest theories with C^2 implications being applied to combat analysis by military analysts. In their paper, "Chaos And Command: Contemporary Science and Leadership in the Nelson style," Robert Artigiani and Michael Gaffney examine the highly successful leadership style of the English Admiral Horatio Nelson within the context of chaos theory. The paper examines how a leader can instill a common idea of how a battle should be fought and then give his subordinate commanders sweeping authority to exercise their initiative as they see fit in order to accomplish the objectives of the battle. This "chaotic" style of leadership proved to be very successful for Admiral Nelson and his "band of

brothers" in their various battles. It is a new and unique application of chaos theory to help think about combat, command and decision making.

E. DECISION AIDS

While decision aids have been used for many years to support tactical decision making, the complexity of the models used has evolved considerably from the days when a maneuvering board was the primary tool aboard naval vessels and aircraft. Microcomputers and database management systems have led to the development of computer-based decision support systems which enable commanders to integrate large volumes of information.

Several students at the Naval Postgraduate School have developed decision aids in theses. For instance, Professor Donald Gaver describes three decision aids in his article, "Naval Tactical Decisions Under Uncertainty: Some Case Studies." NPS students applied probability and statistical methods to assess such decisions as target selection, ranging and radar employment.

Assigned readings help illustrate other attempts at creating or modifying decision aids to model combat or other factors involved with combat. In his paper, "On the Distribution of Combat Heroes," J. J. Bolmarcich examined what may be called "the theory of the expert." He found that in a cursory examination of two historical examples of combat kills per combatant, a trend appeared where a few of the combatants achieved the majority of the kills while the majority of the remaining combatants achieved little or no kills. He wondered that if an athlete can improve his or her performance by practice and experience, could not a combatant become more skilled and adept at combat over time? In order to try and verify his supposition, he used the Multivariate Homogeneous Polya Distribution

scheme as a decision aid to model combat kills in five cases: US Navy and US Air Force air-to-air kills in Vietnam, US Submarine kills of Japanese ships in World War II, German U-boat kills of Allied ships in World War II and Israeli tank kills of Arab tanks in the 1973 War. Through the use of the Basic Polya Urn Mechanism, Bolmarcich shows that balls, randomly tossed into a number of urns will tend to accumulate more in a just few of the urns. The probability calculations were then applied to the case studies by likening the balls to kills and urns to combatants. Additionally, Bolmarcich utilized the Boze-Einstein equation which describes a natural phenomenon of "capture" in physics as the neutral or natural amount of effect of past success on future success. His results showed a definite relationship between combat experience and number of kills.

James Dunnigan is a commercial wargamer who has an enormous amount of experience concerning both weapon and human performance in historical battles. His paper, "Inserting the Human Factors into Combat Models," lists his conclusions regarding the effects of human factors and how to treat them in models. He asserts that human factors, such as experience, training, fatigue, etc., are crucial to realistic combat modeling and can be successfully modeled. Most of these models are based upon historical analysis of battles. Additionally, he provides some examples of commercial software that can be adapted to include human factors.

Another Dunnigan paper, "The Failure Rate of Division Commanders After 90 Days of War," is an examination into the "sacking" of combat leaders throughout history for failure or incompetence at the outset of war. His research examines statistics from World War I, World War II, Vietnam, the American Civil War and others.

George Schecter, James Richards and Henry Romberg presented their paper, "Tactical Deterrent Effects Model" at the MORS mini-symposium in 1989. It is one of the few efforts to use data and model the phenomenon of combat suppression. Specifically, it addresses the effects of mine systems in combined arms engagements to yield measures of tactical deterrence.

F. RELEVANCE TO FURTHER CURRICULUM COURSES

Theories, modeling techniques, measures of effectiveness, etc., all affect successful analysis. Models/wargames/simulations must be designed and crafted in such a way as to provide the best data, advice and vicarious experience for the commander and his forces. It is up to the combat modeler to do that, but general statements about analysis or abstract models of combat phenomena are limited in their value. In this chapter, we have shifted from the general and abstract to a few examples that are both current and slightly more specific.

These actual working military models/wargames/simulations and some recent "grand-scale" theories of command in combat show some specific characteristics of models and statistical studies with emphasis on combat decision making and the commander/staff perspective. Throughout the Joint Command, Control and Communications curriculum, numerous models and studies will be presented, examined, tested and in some cases played. Although the specific models/wargames/simulations will change and be updated and improved due to changing priorities, different instructors and curriculum objectives, here is a list of some of the "larger" models used in courses within the curriculum:

OS 3603: Joint Theater Level Simulation (JTLS)
Janus (T)

CC 4003: Research Evaluation System Analysis (RESA),
Tactical Tic-Tac-Toe (T4),
Headquarters Effectiveness Assessment Tool (HEAT),
Coordination in Hierarchical Information Processing Structures (CHIPS)

This list is only of models actually "played" by students. A complete list of models/wargames/simulations studied and examined in the curriculum would be too lengthy for inclusion here and quickly become outdated.

IX. COMMAND AND CONTROL SUMMARY REMARKS

AIM:

Relate this course's concepts to the study of command and control. Ensure the student recognizes the strength and limitations of combat modeling techniques and analysis of results as an aid in the accomplishment of combat missions and objectives. Summarize the relationships previously presented between the course in combat modeling to future courses to be taken in the Joint Command, Control and Communications Curriculum.

OBJECTIVES:

- Relate command and control to a decision process
- Discuss the commander's distribution of combat power spatially, temporally, and functionally
- Understand the application of combat modeling to the goals of combat

A. ROLE OF COMMAND AND CONTROL

The purpose of this course has been to give the student a perspective of combat models based on a theory of combat and a precise, unambiguous set of definitions for command and control. We will now attempt to draw key concepts together so that the students of command and control understand role of combat modeling with respect to other courses in the Joint Command, Control and Communications curriculum.

No matter which definitions are used to discuss command and control, all of them say that a command and control <u>system</u> is an the means of a commander's decision and execution <u>process</u> with equipment, procedures, etc. Recall that in Chapter II, "command" is a <u>function</u> which deals with organization, motivation, decision and execution. "Command-control" is the process by which the commander makes decisions in order to perform his functions.

B. DISTRIBUTION OF COMBAT POWER

The final conclusion from Chapter II was that the commander's actions create combat power by activating combat potential. The purpose of the command-control process can be expressed as the commander's ability to create and operationally distribute his combat power spatially, temporally and functionally in order to accomplish his mission. An effective command and control process results in the wise use of combat potential to generate the combat power which achieves the objectives or aims of the unit in the face of a thinking, reacting enemy.

The role of combat models is to help the commander examine the situation before him to help him best distribute the available forces in his command. Neither a model nor anyone on the commander's staff can replace the commander's

intuition or estimate of the situation in combat or ignore the importance of this estimate in historical conflicts. However, a combat model as a decision aid will provide a commander with additional information to help him assess the situation, thus allowing him to effectively activate his potential and distribute his combat power in order to achieve his goals.

C. GOALS OF COMBAT

In his paper, "Command and Control Within a Theory of Combat," Wayne Hughes proposed three combat goals in order of importance:

- Achieve the assigned mission;
- Achieve the mission at reasonable costs;
- Recognize mission accomplishment in terms of means and ends.

The importance of combat models can be examined from the perspective of these goals.

In assigning his subordinate a mission or objective, the superior commander must first assess the situation and determine how many units will be required to accomplish the mission (how much force must be assigned to succeed). The superior commander may have his own intuitive feeling for the situation but he must be able to process intelligence data and other information to determine the combat potential required.

In contrast to the superior commander, the subordinate tactical commander executes his orders and completes his assigned mission using a number of "tools": tactical decision aids, doctrine, his standing orders, his own operation order, and guidance regarding environmental factors and equipment. The successful tactical commander will not only arrive at a decision by applying the most appropriate

decision aid, but will also understand the derivation of the aid so that he may make corrections to fit his assessment of the current situation.

As pointed out by Robert McQuie (see Chapter VII), most historical battles rarely resulted in the complete destruction of the opposing force. A commander faced with achieving an objective wants to be able to determine what "costs" he will permit in attempting to complete his mission. Again, the commander must be able to examine the situation and use some sort of guide for determining whether his assessment of losses (change in potential) is acceptable in the accomplishment of the mission. If the loss assessment is too great, he must change tactics, redistribute his combat potential or reassess his original estimate of losses he can afford. All of the available measures rely on the commander's ability to look ahead, not so much to "predict the future" but to weigh the odds and determine the possible outcomes for various scenarios. As the raconteur Damon Runyon once wryly said:

> The race is not always to the swift. The battle is not always to the strong.
> But that's the way to bet.

Analysis helps you decide how to "place your bets."

Once begun, the determination of when a mission is finished or whether or not an objective has been met depends largely on the commander's assessment of the overall situation. Throughout the later chapters of this text, the results of Lanchester-type attrition models have been shown lacking in their ability to account for the effects of such significant concepts as: territory lost or gained, suppression, maneuverability, domination and surprise. It becomes apparent that the outcome of a battle often must be measured in terms other than attrition. The role of the commander is to determine the processes which will help him to

achieve dominance over his enemy through the effective distribution of his forces spatially, temporally and functionally.

D. COMBAT ANALYSIS AND THE C3 CURRICULUM

The purpose of this course is not to generate operations analysts who are experts in creating combat models. Rather, the course was designed to emphasize the importance of combat modeling in the command and control process and help students understand which factors determine the extent to which a model is adequate, in specific situations, to aid decisions and their execution. The course emphasizes the applicability of different modeling techniques, in different combat environments, to generate useful decision aids for commanders.

In subsequent courses in C^2 Architecture Design and C^2 Systems Analysis, the student will study the applications of combat modeling and analysis techniques currently used today. In designing a C^2 architecture, the preliminary goal is to determine the needs of the commander in order to best design an organization which will aid him in his decision making and execution effectiveness. A properly developed organization is key to a commander's ability to motivate and activate his forces, best distribute the forces and be able to monitor the execution of his decisions.

Systems design and analysis must be based on achieving maximum system effectiveness in order to increase the combat power of forces. Models which evaluate the usefulness and effectiveness of systems in the generation and distribution of combat power are based on the techniques presented in this text. Proper model selection and analysis for a system's design and development can

save the taxpayers the cost of poor systems and prove the need for, and effectiveness of, good ones.

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